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Submarine combat systems engineering project capstone project

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Submarine Combat Systems Engineering Project
Capstone Project

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06 June 2011

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Prepared for: Chairman of the Systems Engineering Department in partial fulfillment for the degree of Masters of Science in Systems Engineering

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14. ABSTRACT
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One current thrust for the technical community within the United States Navy Submarine Force is how the technical community can sensibly implement Reduced Total Ownership Cost (RTOC) ensuring affordability of the next generation Submarine CCS. Since the submarine platforms play a significant role in the theater level engagement chain, the submarine combat system effectiveness cannot adversely impact the success of the overall theater level engagement chain.

A central theme of our research is to show the effects that lowering combat system manning has on the overall effectiveness of the submarine engagement chain. To assess the submarine combat system effectiveness, this project evaluates the functional data flow through the detect to engage scenarios to evaluate the changes in the level of man versus machine and the system parameters to determine the feasibility of replacing personnel with automated data processing systems, logic and algorithms.

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ABSTRACT

The Combat Control System (CCS) construct developed using a systems engineering approach, when implemented, will provide significantly increased levels of automation. This high level of automation, will allow a reduction in manpower from 48 in the current Virginia operational base-line to 23 with four CCS operators per shift and an average utilization of 34.1%. This 52% reduction in manpower utilization will provide a more rested and effective crew, increasing safety of ship, while potentially saving the Navy $41.7 million per year.

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The Newport and Bayview cohort team would like to recognize the professors at the Naval Postgraduate School (NPS), the project advisors, stakeholders and interviewees who all played a part in shaping this project. Without their knowledge, commitment and patience the contents of this capstone would not have been possible.

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Lastly, our team would like to thank our families who patiently supported our efforts while understanding the interruption would only be temporary.

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EXECUTIVE SUMMARY

The Combat Control System (CCS) construct developed using a systems engineering approach, when implemented, will provide significantly increased levels of automation to perform strategic and tactical missions with greater platform Situational Awareness (SA), contributing to the success of the overall theater level kill chain. This greater level of automation allows for a reduction in manpower from 48 sailors in the current Virginia Class operational base-line to 23 sailors, with four CCS operators per shift and an average utilization of slightly greater than 34.1%. This 52% reduction in manpower utilization will provide a more rested and effective crew, while increasing safety of ship and potentially saving the Navy $41.7 million per year.

One current thrust for the technical community within the United States Navy Submarine Force is how the technical community can sensibly implement Reduced Total Ownership Cost (RTOC) ensuring affordability of the next generation Submarine CCS. One of the important operational cost drivers is manpower, which can be reduced by decreasing the number of personnel required to operate the Submarine CCS. However, reductions in CCS personnel must be accomplished while maintaining the combat system effectiveness. Since the submarine platforms play a significant role in the overall success of the theater missions the submarine combat system effectiveness cannot adversely impact the overall theater level engagement chain. Due to the nature of the submarine missions, the Rules of Engagement (ROE) may not require a target "kill" but may require engagement in a role to track for the purposes of monitoring. For this reason the submarine engagement chain can perform the tracking or kill depending on the ROE.

There are many gauges by which to measure Total Ownership Cost (TOC) but the single largest driver is the Direct Unit Cost (DUC) associated with manning [GAO, 2003] [Allison, 2000]. The current NAVSEA focus in advancing existing individual subsystems and low-level tools has not actively considered decreasing manpower, but rather increasing and improving system capabilities for the operator to conduct various aspects of tactical missions.

To address the feasibility of reduced manning a new systems engineering approach and Concept of Employment (CONEMP) was developed to support the current platform level engagement chain. To determine the feasibility of this new construct in reducing CCS personnel, a system model was developed and evaluated by varying levels of man versus machine, the number of men supporting the CCS and the effectiveness of the combination of software algorithms and machine power.

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I INTRODUCTION

The military importance of the United States Navy (USN) submarine force has been articulated in the Congressional Research Service (CRS), Congressional Budget Office (CBO) and Government Accountability Office (GAO) reports [Navy, 2005] [CBO, 2002] [GAO, 2001]. The military value of submarines has long been recognized by foreign military leaders. This strengthens the need to retain a sustainable submarine force and subsequently a capable Combat Control System (CCS) [China Naval Modernization, 2009].

With the cost of construction for the fast attack and ballistic missile submarines receiving the attention of Congress, the overall Life Cycle Cost model needs to be examined to ensure appropriate construction, affordable combat system acquisition and reasonable operational suitability costs [Navy, 2010]. Highly capable and affordable combat systems are key components to ensure realistic submarine construction and operations costs.

Due to the sensitive nature of this project, all values used in the analysis were derived from open source documentation. These assumptions are used throughout the text and are listed in Appendix B. As this report is an academic exercise, it is intended to demonstrate the team's ability to plan and execute a project from a systems engineering perspective. This report is intended to provide a construct from which a separate and fully implementable project can be developed utilizing classified parameters and values.

A. SUBMARINE COMBAT SYSTEM ENGINEERING PROJECT

The Submarine Combat System Engineering Project (SCSEP) is an information processing system that translates raw sensor data into actionable information used to convey an understanding of the operational environment to the supervisors. The combat system is comprised of both the machines that process the data and the operators that control the machine and translate the data into information. The present Concept of Operations (CONOPS) for the legacy combat system requires a contingent of specialized, well trained operators to gather and translate the sensor data. The intent is not to replace the CCS operators and their human decision making process, but rather to realize efficiencies in machine-based perception and comprehension by utilizing the processing power of computers in conjunction with people.

B. BACKGROUND ON THE ENGAGEMENT CHAIN

A central theme of this project is the submarine engagement chain illustrated in Figure 1. An overview of the engagement chain and key terminology used throughout this report is included to provide definitions and context for the reader. The engagement chain is the process for search, detect, identify, track, decide, engage and assess contacts in the environment. As depicted in Figure 1, the engagement chain is based on a modified version of Bloye's kill chain, which is defined as a "Detect-Track-Identify-Approve-Launch-Control-Assess" process [Bloye, 2009]. This report does not concern itself with the actual kill. However, it focuses on the on-board processing from detection through the decisions involved with engagement rather than focusing on the engagement of contacts.

Figure 1 Engagement Chain

The term sensor is used throughout this report and defined here for context. Sensors are devices which measure energy in the submarine operating environment and converts it into information that the operator can evaluate as part of the decision making process. Sensors include sonar, imaging, Electronic Surveillance (ES) and communications. These sensors passively detect contacts, which emit acoustic, electromagnetic, visual, infrared, and radio frequency energy. Assuming that active sonar is rarely used in operations, only energy received by passive sensors is included. A contact can be sensed by the system as either surface or subsurface.

The first step in the engagement chain is the search process, which involves the use of submarine sensors to receive energy to detect contacts. As a result of the search process, the second step, detect occurs when the operator validates an incoming contact. The challenge for the combat system operator is to recognize and discriminate between contact details, such as Signal to Noise Ratio (SNR) in decibels (dB), bearing and frequency content. The sensing of energy is necessary, but not sufficient, to assess if there is a successful detection.

The third step in the engagement chain has the objective of identifying the contacts based on the contacts' acoustic frequency components and location in the environment. Each contact is also uniquely categorized into classes (e.g., warship, merchant, pleasure craft or biologics) by its frequency content, bearing, bearing rate and range rate. Each contact is assigned a unique contact number to differentiate contacts within the combat system.

During the identification process, the watch team monitors the categorized contacts for Contacts of Interest (COI) or Contacts of Concern (COC) [DEVRON-12, 2011]. A COI is any contact that requires the attention of the contact management team. A COC is any contact that presents a risk of counter detection, hostile engagement, or collision [DEVRON-12, 2011].

A COI is determined by specific operational tasking or the potential to impact ownship safety or security. Contacts that are identified as COIs are actively monitored by the watch team. A COI is elevated to a COC if any of the established thresholds are exceeded [DEVRON-12, 2011].

The fourth step involves initiating the track process. During the track process, the contact management team uses the data from the submarine sensors and subsystems to determine and maintain the course, speed, and range of a contact, or multiple contacts.

The information gained from the tracking process is utilized to predict collisions or to employ the weapons system to develop targeting and firing parameters.

The fifth step is the decide process of the engagement chain, which is the responsibility of the Commanding Officer (CO) and executed by the Officer of the Deck (OOD). He must maintain situational awareness (SA) that will allow him to decide what action is required. During the decide stage, the OOD must make a decisive action to either avoid or engage a COC. If the OOD decides to avoid, the submarine is actively maneuvered by changing course, speed, or depth. The sixth step is the engage process when the CO directs the employment of the weapons systems. The seventh step is the assess process which occurs following the engagement. To assess, the submarine sensors are utilized to determine the outcome of the engagement.

C. PROBLEM STATEMENT

There are many gauges by which to measure Total Ownership Cost (TOC), but the single largest driver is manning [GAO, 2003] [Allison, 2000]. By implementing Reduced Total Ownership Cost (RTOC) within the USN Submarine Force the technical community must manage the affordability of the next generation Submarine CCS. Since one important operational cost driver is manpower, TOC can be reduced by decreasing the number of personnel required to operate the Submarine CCS.

The central focus of our research was on how to lower manning in light of the engagement chain. To assess submarine combat system effectiveness, this project evaluated the data flow using scenarios to evaluate changes in system parameters. The project also looked at the “man versus machine” to determine the feasibility of replacing personnel with automated data processing. Reductions in CCS personnel must be accomplished while maintaining the combat system effectiveness.

The current submarine combat system development process produces products in a two-year development cycle [Stevens, 2008]. This process enables evolutionary changes to each subsystem, and has realized incremental improvements in the following areas:

1. Open Architecture (Networking): Subsystems have been networked together to provide faster sharing of information with hardware independent software [Stevens, 2008].

2. Sensors: More advanced sensors and processing capability have been added [Stevens, 2008].

3. Automation: Automated trackers and “bell ringers” are software algorithms that have been implemented to assist the operator in the detection and classification of acoustic energy or visual contacts [Zarnich, 2006]. Bell ringers are preset thresholds that alert the operator when the threshold has been exceeded The improved system performance is alluded to by Stevens when he points out that the sonar system can turn a sonarman into an expert if they are looking at the right display *and* can interpret a quiet diesel submarine from noisy merchant vessels [Stevens 2008].

While Stevens made it clear that these networked subsystems, advanced sensors and improved automated tools have increased the operator's success detecting contacts, it has not necessarily decreased their workload [Stevens 2008]. These improvements in the systems gives the operator more capability at detecting contacts, but not necessarily a focus on applying automation to reduce the quantity of operators [Stevens 2008].

The downside of this evolutionary process is that even with the intent to eliminate stove-piped programs, each subsystem remains developed as part of independent modernization programs. [Toth, 2010] Therefore, it is not the performance of the sensors and/or automation of the existing stove-piped processes that needs to be considered, but rather the method by which the resultant data is utilized.

An examination of the platform-level engagement chain steps (functions) is needed to reevaluate the workflow and develop a new CCS CONEMP to reduce manning. Reduced manning levels must be reached without degradation in the overall submarine effectiveness. This new approach to workflow will require a new construct that defines how subsystems come together to form a viable, tactical CCS system. An assumption of this project is that a paradigm shift will be required in the way the systems are utilized and organized, resulting in higher “people-ware” efficiencies.

D. APPROACH OVERVIEW

The purpose of this project was to develop the basic concepts of an architecture that could be used as a construct for the next generation of submarine CCS. This report presents a method of reducing the manning of CCS in relationship to the platform engagement chain. This was accomplished by developing a new systematic approach to the analysis of the CCS supporting architecture and coupling it with a new proposed CONEMP. Scenarios were developed that represent the full range of submarine operations. From these scenarios, a stressing case was created to demonstrate that an end-to-end model based on the engagement chain could be developed for the submarine combat system. This model focuses on maintaining mission effectiveness of the submarine CCS, while reducing the number of combat system personnel.

To illustrate the concept of the project, the Department of Defense Architectural Framework (DoDAF) Operational View-1 (OV-1), shown in Figure 2, presents the proposed scenarios for the project. To construct a system model, several assumptions and constraints were formulated to present an unclassified treatment of the project and create a report that is available for public release. These scenarios utilize high contact density and SA to evaluate the effectiveness of the proposed system.

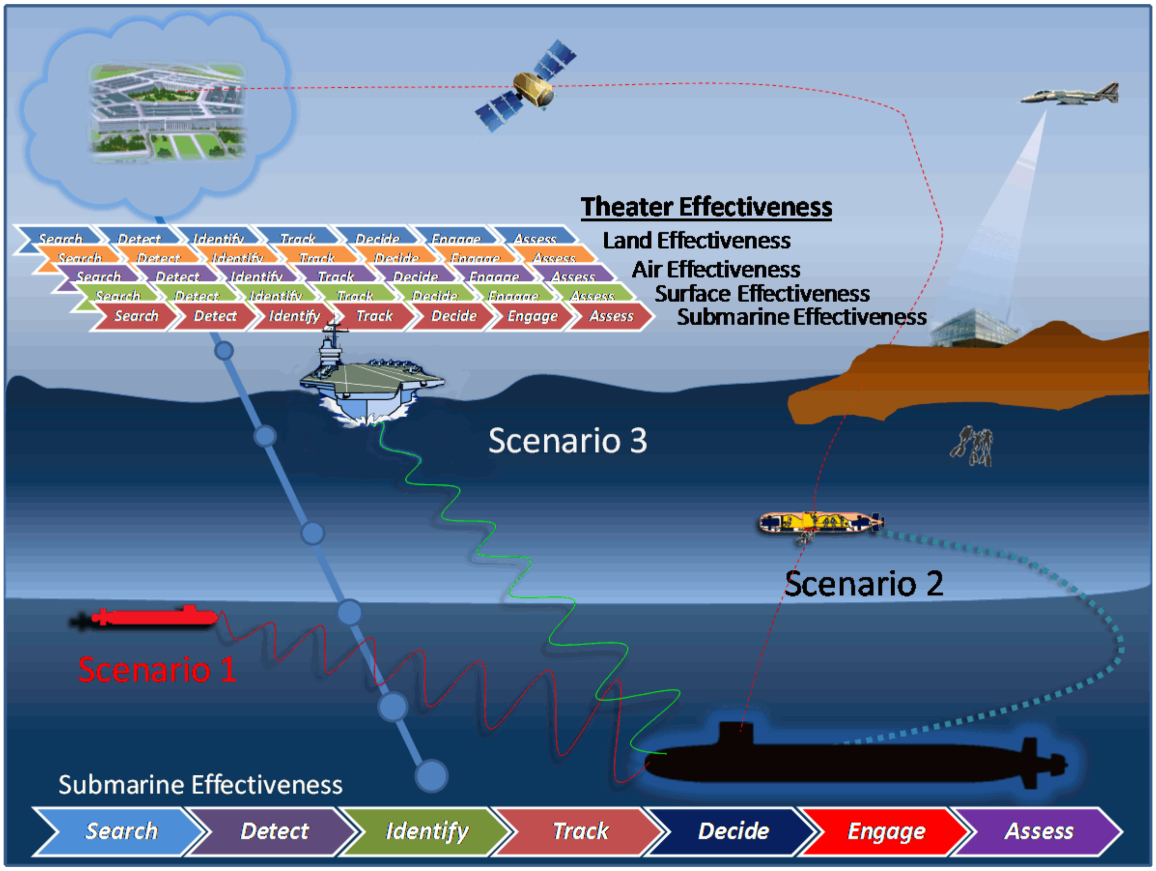


Figure 2 SCSEP OV-1

E. SCOPE

The scope of this project was to investigate a new submarine CCS construct that could reduce TOC and maintain or improve system effectiveness. A high level system model was developed to support mission scenario development, capability definition, and engagement chain analysis. The results include recommendations for future development. Sensor inputs and performance are not taken into account. Sensors improvements are assumed to be incrementally advanced under their own program paths. This study addresses only the CCS suite, with respect to RTOC and effectiveness, as it directly relates to the engagement chain.

II SYSTEMS ENGINEERING PROCESS

The systems engineering process section details the structure that was implemented in the SCSEP to define the problem, identify system tradespace, create the system model, implement simulations and conduct an evaluation of the system model.

A. SYSTEMS ENGINEERING PROCESS

To execute the SCSEP project, the systems engineering (SE) approach detailed in Figure 3 was utilized. This approach is a modification of the International Council of Systems Engineers (INCOSE) State, Investigate, Model, Integrate, Launch, Assess and Re-evaluate (SIMILAR) process, and has been adapted to the scope and scale of the SCSEP.

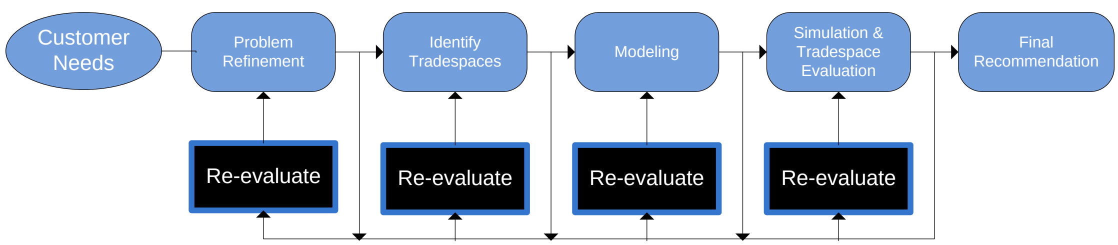


Figure 3 SCSEP Systems Engineering Model

a. *Refine Problem*

Problem refinement involved translating stakeholder's needs and wants into a clear problem statement with prioritized requirements. The significant steps of this phase were:

Interview Stakeholders – Stakeholders were interviewed from the Naval War College (NWC), Submarine Development Squadron 12 (DEVRON-12), Navy Submarine Medical Research Lab (NMSRL) and the Naval Undersea Warfare Center (NUWC) to gather subject matter information, customer wants and customer needs.

Develop Mission Scenarios – Scenarios that are representative of plausible submarine missions were developed based on stakeholder needs. These scenarios were used to outline the scope of the requirements and to evaluate the system performance. The mission scenarios provided focus and the initial details of how to translate the functions and submarine engagement chain activities into the overall system requirements. The mission scenarios were also used to identify the maximum expected contact environment for the simulations, discussed below, as a stress test. This was done to ensure the CCS would be able to run under worse case loading.

Generate and Analyze Requirements – The interviews produced a shipboard functional activities task list. This was compared to the stakeholder wants and needs to formulate a draft requirements list. The Universal Navy Task List (UNTL) was used to as a source for the tasks identified for basic submarine operations, anti-submarine warfare, intelligence gathering, contact tracking and weapons employment.

Refine Requirements – The initial requirements were decomposed into the component elements of the engagement chain. Based on the mission scenarios and the analysis of model outputs, the requirements were refined to achieve the best combination of system parameters.

Develop Measures of Merit (MOMs) – The MOMs are the full set of Measures of Effectiveness (MOEs) and Measures of Performance (MOPs) derived from the stakeholder inputs. From the MOEs, the subset of MOPs were identified to categorize the specific performance metrics. Key Performance Parameters (KPPs) were selected out of the set of MOPs as being the most important. These MOMs are used to measure the goodness of the design.

Determine the relative importance weights of the MOMs – With MOMs defined; the impact of each KPP was determined and assigned a relative weighting factor. These weights were used during tradespace evaluation to provide some quantitative information about the stakeholders needs in relation to the possible performance issues as the tradespace was explored.

b. *Identify Tradespace*

The variables for the overall CCS system model needed to be identified as the basic system tradespace. These model variables required adjustment to achieve the goal of reducing manpower based on the identified requirements. The tradespace consisted of the percent man versus machine used at each workstation and the total number of men available. The overall effectiveness of the system was driven by the combined effectiveness of man and machine coupled with the allocation of workload (percent man or machine) at each workstation supporting CCS.

c. *Perform Modeling*

The modeling phase involved developing three models of the CCS:

Capability Based Architectural Model – Based on the capabilities and functions identified during the requirements refining process, a capabilities based architectural model was developed. The result of the capability based architecture was used as the basis of the simulation model. This architectural development included determining and understanding the probabilities of the contact status as output by each stage along the processing path. This model includes the tradespace discussed previously.

Probability Based Simulation Model using ExtendSim® – ExtendSim® is a modeling and simulation application that was used to simulate the overall performance of the system based on the model inputs. This model represents the construct for the proposed CCS architecture. Based on the data flows, contact attributes, and probabilities developed in the capability based architectural model, a separate model was generated to simulate the CCS. The model was used to provide data for analysis of the tradespace. For the simulations, CCS was implemented as a probabilistic abstraction of the CCS capabilities, and as such, represents the construct for the proposed CCS architecture. The output of the probabilistic model was used to compare the KPPs, and ultimately any necessary adjustments that needed to be made to the overall system requirements.

Cost Model – A cost model was used to quantify representative savings for the report. The results of the system model analysis in terms of personnel reduction will be utilized as the basis to determine the potential savings per person, per platform. The resulting data will be used to calculate an overall yearly and potential ten year savings. The overall intent was to reflect the impact of system manpower reductions as a function of TOC.

d. *Evaluate Tradespace*

In this phase, the worst case scenario was used to stress the model. The results of the model run were compared to the system requirements and the variables in the tradespace were adjusted as necessary. The output of this phase is a recommended set of machine constraints, manpower needs and "man versus machine" utilization. The major steps were as follows.

Executed Simulations –ExtendSim® software was used to develop an executable probabilistic model of the CCS system. This executable model was run to simulate the performance of the CCS and to estimate system performance, under varying operational parameters. The ExtendSim® simulation model was run with 64 different combinations of input parameters, as discussed in Appendix C.

Determined Trade Offs – The team performed trade off analysis by analyzing the output of the simulation runs. The output of the probabilistic model was used to compare the KPPs and make any necessary adjustments to the model variables to meet the overall system requirements.

e. *Final Recommendation*

The final recommendation identifies the way ahead for the CCS system based on the enabling technologies, potential follow on work and organizational changes to support fielding the CCS system. These recommendations were based on the results of data analysis and the overall conclusions.

III STAKEHOLDER ANALYSIS

The project stakeholder analysis consists of two parts the project stakeholders and the submarine CCS stakeholders. The project stakeholders provided contributions to the report content for the SCSEP project. The submarine CCS stakeholders are the subject matter experts that sponsor, acquire or use the SCSEP.

A. PROJECT STAKEHOLDERS

Project stakeholders include the student team members from Naval Undersea Warfare Center Division Newport RI (NUWCDIVNPT) and Naval Surface Warfare Center Division Carderock Detachment (NSWCCD) Acoustic Research Detachment. Advisors and mentors from the Naval Postgraduate School (NPS) and NUWCDIVNPT also provided advice and feedback during the course of the project. The student team members performed research, conducted modeling and analysis, and developed this report. During the project, the student stakeholders interacted with the NPS advisors weekly to provide status and solicit feedback. Additionally, the NUWCDIVNPT Chief Engineer (CHENG) served as a stakeholder and provided feedback and guidance to the team periodically during the conduct of the project. IPRs were conducted that gave the opportunity for all stakeholders to provide feedback and recommendations on the project. These interactions with the project stakeholders served to provide real time feedback to the team allowing for valuable input and guidance for the project. Table 1 outlines the major project stakeholders:

Name	Community of Practice	Role
Dr. Jeffrey Beach	NPS	Advisor
John Becker	NSWCCD	Project Team Member
Shaun Cookinham	NUWCDIVNPT	Project Team Member
Shawn Goode	NUWCDIVNPT	Project Team Member
John (Mike) Green	NPS	Advisor
David Rhodes	NUWCDIVNPT	Project Team Member
Denman Sweetman	NUWCDIVNPT	Project Team Member
David Toth	NUWCDIVNPT	NUWCDIVNPT CHENG
Mark Wasilewski	NUWCDIVNPT	Project Team Member
Samuel D. Winograd	NUWCDIVNPT	Project Team Member

Table 1. Project Stakeholders

B. STAKEHOLDERS FOR THE SUBMARINE COMBAT CONTROL SYSTEM

Stakeholders for the submarine CCS are the people and organizations that would be the real world acquirers, developers, and users of the submarine CCS. At a high level these stakeholders fall into one of three categories: the user community, resource sponsors, and the acquisition community.

Name	Subject Matter Expert (SME)	Role
User Community	DEVRON-12	Submarine CCS Tactical Procedure Development
	NWC	Instruction and training of user
	NSMRL	Psychological and Physiological analysis of users
	Former Fleet reps	Submarine CCS user
Resource Sponsors	Articles on Submarine Cost	Submarine Warfare Division (N87)
Acquisition Community	Student Team Members	NAVSEA PEO SUBs

Table 2 Stakeholders for the Submarine Combat Control System

1. User Community

The user community is comprised of those that utilize and employ the system, instruct and train the users to employ the system, as well as study and monitor the psychological and physiological analysis of users.

In order to understand the needs of the submarine crew that utilize and employ the system, interviews were conducted with former submariners, as well as representatives of the NWC, NMSRL and DEVRON-12. During the interviews with these subject matter experts, there were five common themes: data confidence, data timeliness, SA, trust of the algorithms and the limitations of human operators.

2. Resource Sponsors

Resource sponsor requirements were defined in terms of MOMs to capture the overall needs of the submarine force. The establishment of the MOMs included MOEs and MOPs which reflect the importance of the Fleet needs. The RTOC analysis performed was applicable only to submarine personnel for combat control and attempt to reduce the cost of the CCS to the Resource Sponsor. A cost model was used to illustrate the cost savings that could be realized by the sponsor.

3. Acquisition Community

The Program Executive Office Submarines (PEO SUBs) and Program Acquisition Resource Managers (PARMS) at the Naval Sea Systems Command (NAVSEA) comprise the acquisition community for the submarine platforms and the CCS. Each team member used their experience from years of supporting the PARM in technical oversight roles and in participation in planning and decision meetings to provide a perspective to the project from the acquisition community.

IV CONCEPT OF EMPLOYMENT

The proposed CONEMP is designed to reduce the manpower needs for the CCS, while maintaining system effectiveness.

The fundamental system model of the CCS is shown in Figure 4. This model provides context for the construct developed in this report, as well as providing context for comparing the current CCS CONOPS with the proposed CONEMP. In this systems model, contact energy is received from non-acoustic sensors (ES, Automatic Identification System (AIS), and imaging) as well as acoustic sensors (sonar).

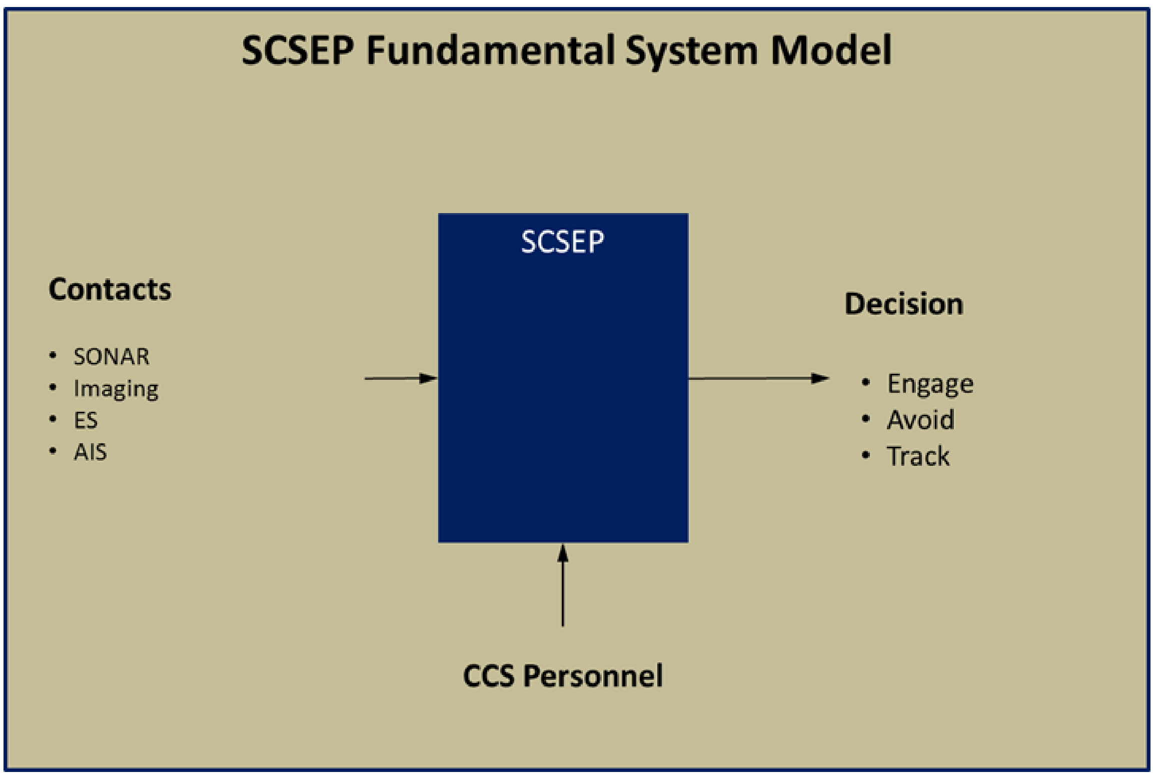


Figure 4 SCSEP Fundamental System Model

Once sensor data is received, the operators must interpret, and correlate the data from the multitude of sensors into information that can then be provided to the supervisors, allowing them to form a SA picture. Forming and maintaining the SA picture with the current CONEMP is operator intensive.

The intent of the proposed CONEMP is to increase utilization of a machine-based infrastructure (algorithms, data processing, heuristics and machine learning) to process the received acoustic and non-acoustic data as though it were a compliment of expert specialized operators. To achieve an expert level of understanding, the lowest level data is assembled and analyzed using Endsley's SA model [Endsley, 2006]. The data must be recognized and understood, and a solution provided to the decision makers. The role change proposed for the SCSEP operators will transform them into data verifiers, as opposed to their current role as data gatherers. The data processing algorithms must effectively present the correlated data as information to the operators. The operators then verify the information and present the information to the supervisors to decide and act upon. The intent is not to replace the human decision making process, but rather to realize efficiencies in perception and comprehension by utilizing the processing power of computers in conjunction with people. In this paradigm, the sensor operators are personnel who have collective Knowledge, Skills, and Abilities (KSA) from each of the CCS system elements that enable them to assess and communicate the threat profile to the supervisory structure. The employment of the particular capabilities is dependent upon the intended mission, so the operator must be knowledgeable in analyzing the output of various sensors.

For this project, three mission-based scenarios were developed, and then merged into a single worst case scenario. During these major shipboard evolutions, the SCSEP model provided an assessment of the received sensor data and prioritized the threats as a function of range and target motion. If the model indicates a probable collision, the CCS operators are notified and appropriate corrective action can be taken.

These three scenarios were used in conjunction with the proposed CONEMP to assess the models developed for the project to ensure the concept was modeled correctly. The level of man and machine was then varied to compare the effectiveness of the current CONEMP with varying implementations of the proposed CONEMP.

A. SCENARIO CONSTRUCTION

Representative scenarios were generated in order to frame and bound the conceptual idea, and to provide a context for development. They focused on Ship Safety/Self Protect functionality and maintenance of local operational SA from on-board sensors and off-board intelligence.

The basic mission flow consisted of receiving tasking from the theater commander. The platform then transited to the identified mission area while maintaining SA and contact avoidance. While in transit and on mission, the combat system team continuously maintained the SA necessary to convey to the command structure all impending issues in a prioritized manner. The SA was conducted by the use of range, contact type and course/speed parameters to assess the potential threat picture. The stages of the operational sequence diagram that was derived to develop the mission scenarios are shown in Figure 5 and defined in this section.

From the transit, the platform is tasked to execute the mission. Each mission requires the detection, identification, tracking, decision making, engagement or avoidance and, if applicable, the assessment of the engagement. For each of the three scenarios analyzed the execution components for the scenario are identified.

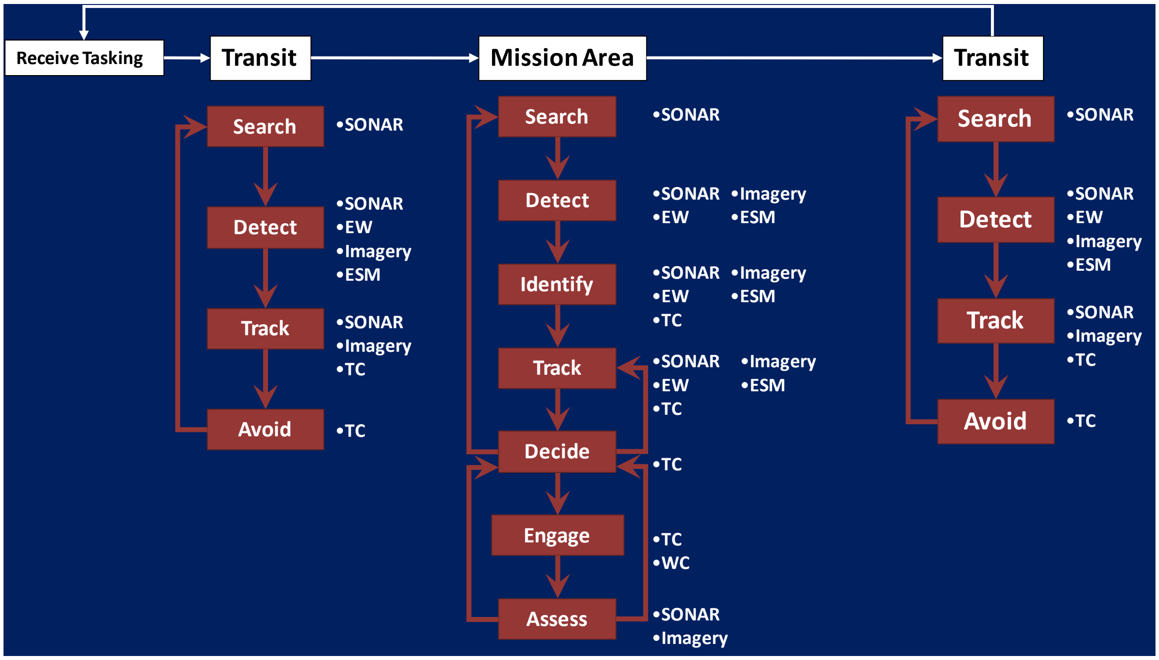


Figure 5 Mission Scenario Construct

The following sections outline an overview of each of the three scenarios used. Each scenario is assumed to consist of port egress and transit on the surface until the dive point. The surface transit presents the case where all of the sensors are utilized, including sonar, imaging, ES and AIS. The anticipated surface transit contact loading has the potential to receive significant numbers of simultaneous contacts. The task for the combat system personnel during the transit is to deconflict the tactical picture and ensure that the command structure has an accurate representation of the situation.

Similarly, during each mission deployment it is assumed that the platform must surface to Periscope Depth (PD) either to support the mission directly or to receive radio broadcast messages for tasking assignments and Rules of Engagement (ROE). These evolutions present cases where all sensors are simultaneously receiving and processing contact data to reconcile the tactical picture. As in the transit case, the combat system personnel must deconflict the fused contact data to ensure an accurate representation of the tactical picture is presented to the command personnel.

1. Scenario 1: Undersea Warfare

Search, Detect, Identify, Track, Decide and Engage Hostile Combatants

This scenario consists of the ownship ability to locate, track and potentially engage hostile combatants (either surface or submarine) in actual combat. While underway, the sonar sensors make an initial analysis of the environment to establish the contact density and attempt to identify the COI. The system provides a means to track the various contact features. The sensor operators in their new role receive the sensor (sonar or all depending upon depth) data and assembles a comprehensive situational picture. In the event that a COI transitions to a COC, decisions must be made depending on the ROE. Ultimately, the decision must be made to track or engage.

If the decision is made to engage, a fire control solution is calculated for the weapon system(s). The torpedo room is then made ready. Upon firing of weapons, the command and combat system operators confirm the level of success against the target. For surface targets, periscope imagery is utilized. Sonar contact assessment is used to gauge the level of success against submerged targets by verifying the absence of the prior acoustic features, as well as the presence of acoustic information related to target damage or destruction.

Conversely, if the decision is made to track, pursue, or avoid, SA must be maintained for the COC until it is deemed no longer a concern. In the case of a submerged COC, the sonar sensors are utilized to analyze the acoustic signature and monitor the system audio and to recognize the acoustic characteristics that are consistent with a hostile combatant. The ownship watch bill must ascertain the likelihood of the launch of threat torpedoes and determine evasion tactics and countermeasures. In the case of a surface COC, both acoustic and visual sensors may be utilized. At all times, the crew must maintain SA for both the COC, as well as any COI.

The flow for this scenario follows the engagement chain. The sensors receive acoustic energy, imagery or ES depending upon ownship depth. The detection algorithms process the data in the form of initial contact reports. The contact reports are analyzed to identify the frequency contents of data. This interrogation of the data is performed to identify the contact as a COI, COC, or no threat.

The classification of the acoustic, image or ES signatures for each contact allow the operator to categorize a contact as a specific vessel utilizing acoustic or visual means. The classification is in the form of warships (surface or submarines), pleasure craft, merchant vessels or biologics. Once a contact is properly categorized, the process of tracking it through bearing space is initiated. For COI and COC, an automated tracker is initialized. The bearing updates are processed through Target Motion Analysis (TMA) on all contacts. The contact management team is alerted when characteristics within the system ascertain a potential collision or significant threat posture exists. The tracking process can continue for great lengths of time depending upon the tasked mission. The system also must determine the threat posture based on the ROE. If the mission presents the potential of hostile threats, the system posture must be set to analyze clues and report out threat conditions without operator interaction.

(a) Decisions are necessary based upon the recommendations. In the case of an active engagement, the Fire Control solutions are calculated for COCs and the ROE are verified. Then the CO must determine whether to engage, avoid or track the contact.

(b) To engage, the Fire Control solutions are sent to Weapons Control (WC) for programming weapons. The COC TMA solution (range and bearing) estimates are used to establish the final firing solution. The system operator preprograms the weapons and seeks permission to fire weapon(s).

2. Scenario 2: Special Operations Force Delivery

Covert Entry into Hostile Waters

This scenario consists of a need to deliver SOF covertly into hostile waters. To achieve the objective of the mission requires comprehensive SA and understanding of the tactical picture. There is reliance on sonar, radar, imagery and satellite communications for surveillance. Ownship will enter shallow water, release a Sea, Air, and Land (SEAL) team and covertly exit the area. The model used for this scenario includes the need to cross a shipping lane to present the system with a high contact density problem, which stresses the system operators contact TMA, and data fusion aspect.

The primary objective is to deliver the SEAL team and retrieve them upon completion of their mission. Following the SEAL team retrieval the ownship platform must return through the high contact density shipping lane..

The flow of this scenario is as follows: Ownship must enter the Mission Operating Area. To achieve covert entry, the system must accurately search, detect, identify and track all contacts within the search space. The operators must trust the contact information and understand the consequences of being discovered. While ownship is deep, sensor operators receive and prioritize all initial contact reports based on the characteristics. While the submarine is crossing a shipping lane and deep, sensor operators receive and prioritize all initial contact reports. When in the littorals and at PD, sonar is used in conjunction with imagery and ES to verify the contact profile.

Once a vessel is properly categorized, the process of tracking it through the use of bearings only TMA. For COI and COC, a means to track the contact is assigned via automated tracking. The bearing updates are processed through TMA on all contacts. The contact management team is alerted when characteristics within the system ascertain a potential collision or significant threat posture exists. The tracking process can continue for great lengths of time depending upon the tasked mission. The system also must determine the threat posture based on the ROE. If the mission presents the potential of hostile threats, the system posture must be set to analyze clues and report out threat conditions without operator interaction.

To execute the mission, the navigator must locate the intended shore-based stations, determine best landing site, and request that ownship enter shallow water. The SEAL team is released to perform their mission. The submarine either exits the operating area or hovers until SEAL team retrieval. Once the SEAL team has been successfully recovered, the submarine exits the mission area.

3. Scenario 3: Advance Battlespace Preparation

Carrier Strike Group Support

This scenario provides a forward presence to the ISR to support air operations. This scenario dictates a need for covert identification of all vessels in the operating area. Various sensors are utilized during this scenario; sonar, periscope, satellite imagery and intelligence. The operators are required to search the operating area to ensure safe carrier operations. Full tactical control and understanding of the environment are required to assemble SA so that accurate tactical picture data will be transmitted back to Fleet Commands.

The flow for this scenario follows the engagement chain and is as follows: While the system is in search mode, the sensors receive energy in the form of acoustic (via sonar), Imagery, or ES depending upon ownship's position in the water column. In the detect stage, algorithms process the data in the form of initial contact reports. The contact reports are analyzed in the identification stage for frequency contents of the data. This interrogation of the data is performed to classify the contact as a COI, COC, or no threat. The track stage utilizes the contact reports as well as the frequency contents to maintain contact location and kinematics. The decide stage uses the tracker outputs and other data (other sensors as well as contact reports, etc) to assemble the SA picture, enabling correct decisions by the crew. Engagement decisions require an understanding of SA, as well as mission requirements.

The classification of the acoustic, image or ES signatures for each contact allow the operator to identify a contact into a specific vessel category utilizing acoustic, electronic or visual means. The classification is in the form of Warships (Surface or Submarines), pleasure craft, merchant vessels or biologics. Once a contact is properly categorized, the process of tracking the contacts through bearing space is initiated. For COI and COC a means to track the contact is assigned via automated tracking. The bearing updates are processed through TMA on all contacts. The contact management team is alerted when characteristics within the system ascertain a potential collision or significant threat posture exists. The tracking process can continue for great lengths of time depending upon the tasked mission. The system must also determine the threat posture based on the ROE. If the mission presents the potential of hostile threats, the system posture must be set to analyze clues and report out threat conditions without operator interaction.

(a) Decisions are necessary based upon the recommendations. In the case of an active engagement, the Fire Control solutions are calculated for COCs and the ROE are verified. Based on the mission objective of ISR, the OOD must determine to avoid or track/pursue, and as a last resort engage the contact.

(b) Periodically, the surfacing to PD is necessary to communicate the results of the mission with the Fleet commanders and to receive further tasking and intelligence information.

B. MISSION EFFECTIVENESS, AND NEED FOR SITUATIONAL AWARENESS

The ultimate goal of the submarine is to complete the assigned mission. Clearly, this has to do with completing mission specific goals assigned by the Navy. However, in order to accomplish these goals there is a set of basic requirements that have to be completed as prerequisites. These basic requirements can be summarized as maintenance of safety of ship and minimizing vulnerability [Bundy, 2010]. This is depicted in Figure 6.

Figure 6 Basic Mission Effectiveness Requirements Hierarchy

As mentioned previously, for the purposes of this project, many of the ancillary activities that occur in the day-to-day workings of the submarine are ignored in favor of only those tasks that take place in the CCS related to the engagement chain.

C. SITUATIONAL AWARENESS

The overall progression of tasks in the combat system is directly related to the submarine warfare kill chain. Figure 7 depicts a modified engagement chain, which shows that the overall goal is typically broader than a simple kill and encompasses many different mission scenarios. For the rest of the report it will be assumed that search was successful and the engagement chain diagrams will omit the search step

A necessary requirement for maintaining the safety of the submarine is situational awareness. SA is basically a matter of comprehending the environment: if you do not understand your environment, you cannot maintain safety, and likely not stealth. Understanding, both the static (landmasses, undersea features) and the dynamic (other ships in the area that might affect us) environment is a key step in assembling the SA picture. Further, comprehension of the environment also enables good decision making about what actions to take to complete the mission successfully, including everything from how to steer the submarine to completing mission tasks. For purposes of this report, we will use the following definition of SA: “The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” [Endsley, 2006].

One key product from the discussions with the SME’s representing the user community was a review and validation of the engagement chain stages shown in Figure 7. It was derived from interviews with retired submarine commanding officers [Bundy, 2010] [Pillsbury, 2010], as well as team experience. The list was confirmed, with minor improvements, by representatives from DEVRON-12 [DEVRON-12, 2011]. This ordered set of stages forms the basis of the engagement chain stages.

Figure 7 Engagement Chain Stages

The activities that make up SA are perceive, comprehend and project. These concepts will be discussed in detail in following sections and will be mapped to the engagement chain.

D. CAPABILITY AND FUNCTIONAL REQUIREMENTS DECOMPOSITION AND ALLOCATIONS

The task list in Figure 7 formed the basis of the decomposition shown in Table 3. In this table, the following pattern is used. The highest (most abstract) level is the engagement chain, which decomposes into the Level 0 (L0) tasks. Not all these tasks were modeled, as they were deemed too detailed and difficult to model and did not add to the overall study. Only the L1 tasks were handled in the model. The L0 tasks could possibly be attempted later.

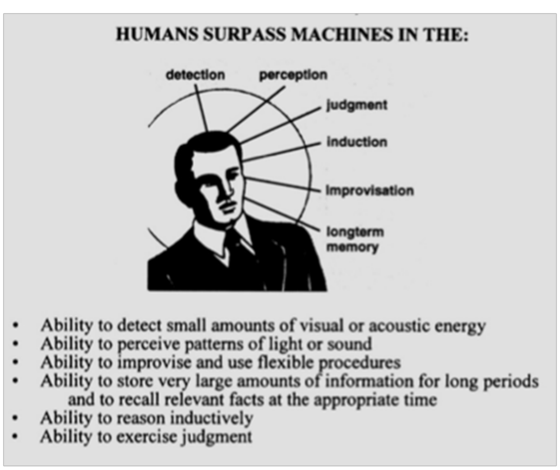
	Engagment Chain Stages →	Detect							Identify										Track												Decide				Engage				Assess
	L0 Tasks →	Optimize Sensors for Environment	Filter Data	Look for Passive Acoustic Energy Trends	Look for Passive Acoustic Frequency Trends	Look for Passive Electronic Energy Trends	Look for Passive Electronic Frequency Trends	Perform Visual Sweeps	Receive Sensor Data (QUEUE)	Analyze Accoustic tonal structure / patterns	Analyze Electronic tonal structure / patterns	Take pictures	Recognize Contact Highlights from pictures	Perform Data Fusion	Classify Contact	Identify Contact	Receive AIS signature	Receive Off-hull Contact Data	Perform Data Fusion	Receive Ownship Data	Assign / maintain Automated Trackers	Manually track through acoustic bearing	Manually track through electronic bearing	Perform Visual Tracking	Develop Contact TMA solution	Predict Collisions	Predict contact loss	Predict Safe Ownship Maneuver	Determine best Firing Approach	Determine Weapon Aiming Data	Perform Data Fusion	Evaluate Situation	Set New Course	Send Targeting data	Preset Weapons	Maneuver	Fire Weapon	Cue Sensor	Evaluate success of engagement
L1 Tasks	Implement Directed Search	X	X	X	X	X	X	X																															
	Process Acoustic Data	X	X	X	X																																		
	Process ES Data	X	X			X	X																																
	Process Image Data	X	X					X																															
	Process AIS	X	X	X	X	X	X	X	X								X																						
	Assess Acoustic Data	X	X	X	X	X	X	X	X	X			X	X	X	X		X																					
	Assess ES Data	X	X					X			X		X	X	X	X																							
	Assess Image Data	X	X	X	X							X	X	X	X	X																							
	Queue Contact Data	X	X			X	X		X									X																					
	Perform TMA																		X	X	X	X	X	X	X	X	X	X	X	X									
	Fuse Data																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
	Develop SA																														X	X	X	X					
	Advise to Do Appropriate Thing																																		X	X	X	X	
	Supervise Doing Appropriate Thing																																		X	X	X	X	
	Cue Sensors for Directed Search																																		X	X	X	X	
	Evaluate success of engagement																																						X
Funct'l Allocation	SONAR	X	X	X	X				X	X					X					X	X	X				X	X	X				X							X
	ES	X	X			X	X		X		X				X		X			X	X		X									X							X
	IMAGERY	X	X						X			X	X		X					X	X			X		X		X				X							X
	Communications	X	X				X		X						X	X		X		X								X				X							
	TC								X	X			X			X	X	X	X	X					X	X	X	X			X	X	X	X	X	X	X	X	
	WC																			X									X	X					X		X		

Table 3 Functional Decomposition and Initial Allocation

The second part of Table 3 provides the functional allocation as to where in the system each of the function takes place. Yellow represents the sensors, which act as service providers to the CCS, providing contact data. The Tactical Control (TC) and WC listed in Table 3 represent the tactical and weapons control subsystems of the CCS. TC and WC are not implemented in the simulations, but rather are noted for future consideration.

E. APPLYING FITTS' LIST

One of the initial attempts at understanding what efficiencies could be generated by applying automation was to apply Fitts' List to each of the tasks in Figure 7 [Fitts, 1951]. While Fitts' List is somewhat dated compared to some of the advances in newer computing technologies and intelligent machine pattern recognition, it was deemed relevant to apply the rules categorization of Fitts' assertions to the combat control sub-system. The practical understanding is that the implementation of a physical system would incorporate more modern technologies capable of discerning contacts in a cluttered environment. According to Fitts' list, the human is superior at perceiving patterns, reasoning inductively and exercising judgment. The machine can help in the area of quick response and deductive reasoning. As long as judgment is left to the operator, the machine as a decision aid can be helpful. This is the reasoning behind the statement in the CONEMP for considering adding machine learning to the CCS algorithms.



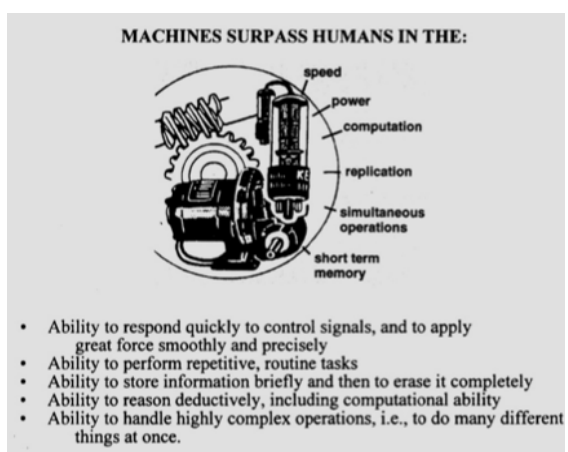


Figure 8 Fitts' List [Schmidt, 2010]

To decide if the thought process was correct, Fitts' List was applied to the Combat System task list. Each task was applied to a corresponding number indicating if people do better (1), machines can do in conjunction with human guidance (2), a machine can perform it better than a human (3), or machines should be able to do it better than humans (4). Figure 7 was modified to include conformance to Fitts' List, as presented in Figure 9.

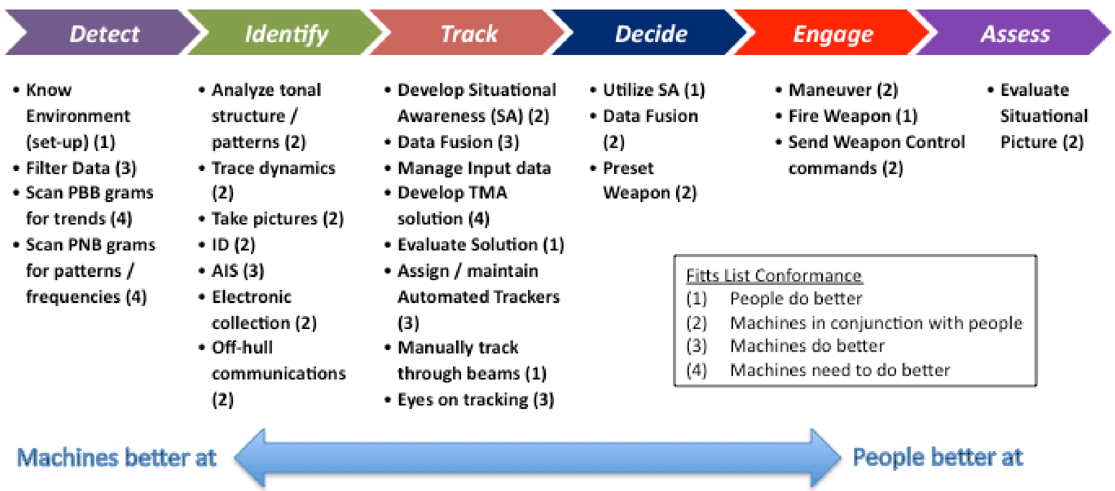


Figure 9 Fitts' List Applied to Combat System Tasks

When the tasks are considered in this manner, it seems that the majority of the tasks on the left are better suited towards machines, where there is more raw data to process. The tasks more towards the right seem better suited to people. There are fewer tasks, more processed data and decisions that require consideration of decision consequences (risk)..

F. KEEPING THE MAN IN THE LOOP

"The Navy is a service of custom and tradition, and ultimate accountability" [Bundy, 2010]. What this meant to this project is that due to the risk of loss of human life, a ground rule was implemented such that the man would not be taken out of the loop completely. Even though it might be feasible to develop an entirely unmanned submarine, it does not seem likely, given risk to life (collateral damage from improperly launched weapons) and an unprotected payload of tactical weapons. The socio-political international consequences of being wrong on a contact are too severe.

The fact that people are better at exercising judgment and reasoning deductively means the man on board the submarine should not be taken out of the decision loop completely. In contrast, an automated system can scan many data sources at once, compute all possible outputs and provide suggestions as tactical decision aids. For example, automation is good at comparing one beam to the next to identify patterns between them, and then comparing the outputs from one sensor to another for consistencies or inconsistencies.

Given the above discussion, the team decided not to eliminate the human aspect from the submarine, but rather enhance the human by using available computing power to maximize their effectiveness. One of the first concepts to come out of this line of reasoning is that the project team needed a way of maximizing the utility of both man and machine, playing to their strengths, which might ultimately change the way the human does his job. In other words, the team realized early on this project could likely cause changes the CCS user’s CONOPS. This mechanism is discussed later in the Man Machine Tradespace section.

G. INTERFACES AND DATA FLOW

The functionality in the engagement chain provides the basis of the interfaces and the data flow. As previously noted, the overall engagement chain tasks follow a SA progression. In general, in order to perform the tasks to complete the mission requirements, the first step is to perceive the environment. The three phases of SA can now be decomposed into individual tasks to be performed. An extremely high level view of the model is presented in Figure 10. This figure also maps the SA activities to the engagement chain.

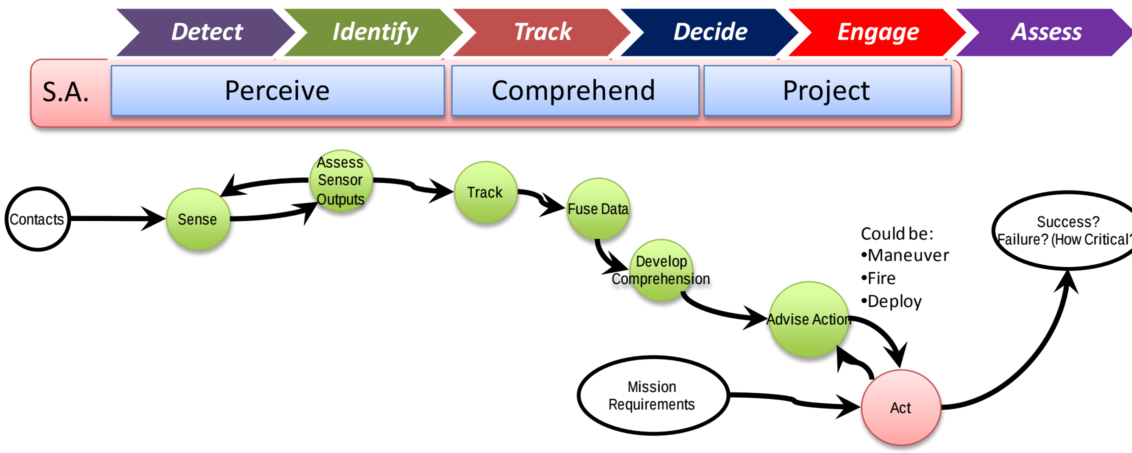


Figure 10 Simulation Model High-Level View

In Figure 10 and Figure 11, the colors refer to how these functions will be implemented. If they are green, either man or machine in a tradespace can perform them. If it is colored red, it is predominantly human performed, although there may be machines acting in an advisory role. Yellow indicates a fully automated function. The circles represent the steps of the subsequent model and the logical mapping of the model.

The first step in the process shows that the sensors had to be considered. The sensors chosen for this report are:

- Sonar, which is broken out into Broadband and Narrowband data streams,
- AIS, which is a transponder system not unlike Identified Friend or Foe (IFF),
- Electronic Sensors, which detect radar systems,

- Periscope imagery.

The latter three can only be used when the submarine is at PD, so that was accounted for in the model as well. Each of these sensors has certain range capability and different output certainties.

The longest-range sensor is passive sonar (this project does not consider active sonar). The problem with sonar is that because of the acoustic nature of the data collected it is difficult to accurately classify and practically impossible to uniquely identify every contact. Additionally, under normal circumstances, passive sonar does not provide range accuracy, and cannot differentiate between multiple contacts on the same bearing. In this model, sonar is broken out into Broadband and Narrowband views of the data. The Passive Broadband (PBB) operator uses what is called the Broadband Gram (BBG). The passive narrowband (PNB) operator uses what is called the Narrowband Gram (NBG).

Classification can be done partially by sonar, but it is often aided by other sensors. AIS works via line of sight, but the problem is that warships and submarines (highly critical contacts) typically do not have their AIS transponders active.

Periscope imagery can be used to determine both bearing and classification. Identification and range of the contact can also be determined dependent on the environment and other variables.

Electronics (ES) can identify the type of radar installed on a contact. With some prior knowledge, this can also help in the identification process.

The model data flow can now be decomposed further to add the specific sensor types, as shown in Figure 11.

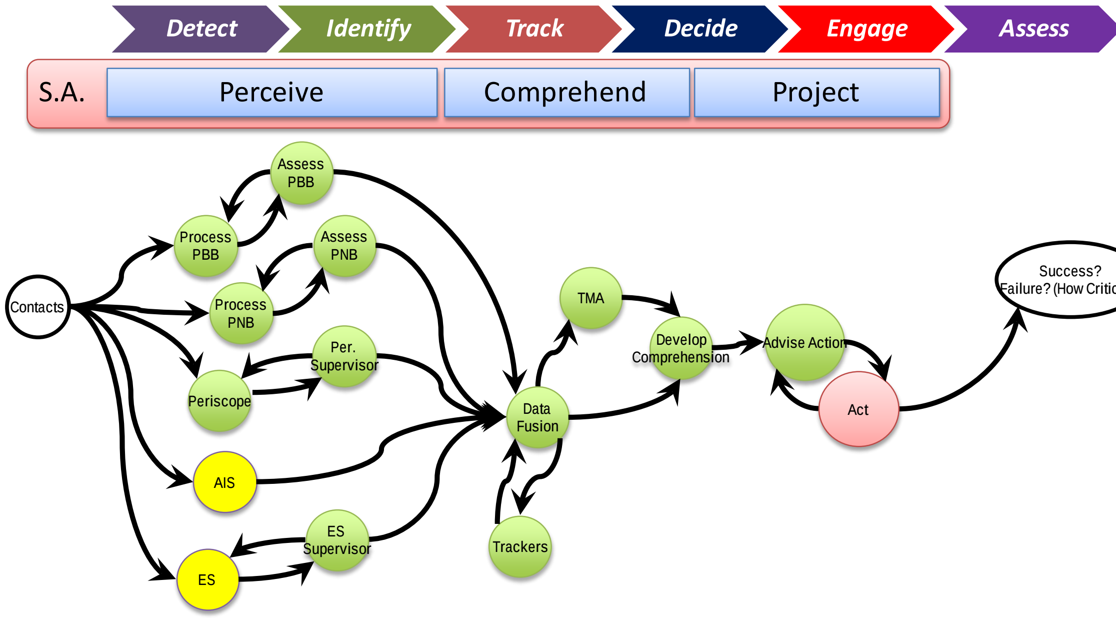


Figure 11 Decomposed Model Data Flow

As mentioned previously, for a successful mission, the crew needs to maintain safety of ship, remain stealthy, and complete the mission requirements. The authors suggest that completing the mission requirements is entirely dependent on how well the SA model is assembled and the projection of the current situation into the future. Successful actions depend not only on the projection of SA, but also on the mission requirements. Since the mission requirements could not be satisfactorily modeled, the actual function “Act” is not modeled.

V SYSTEM REQUIREMENTS

The SCSEP system requirements section defines the MOMs for the system. These definitions include the listing of the MOMs, MOEs, MOPs and KPPs along with the description, metric thresholds and goals, appropriate weighting factors and rationale on how the metric was developed.

A. MEASURES OF MERIT

The systems requirements for this project are reflected in the MOMs, shown in Table 4. These MOMs are sufficient to execute a feasibility study to reduce manning of the CCS, while maintaining system effectiveness. It is expected that any future work to implement the construct defined herein will expand this list of MOMs, as required for full system acquisition. The meaning of each MOM is explained below, with the rationale behind each provided in Table 4. It is important to note that the thresholds, goals and evaluation weights shown in Table 4 are assumed based on the project members' experience within their respective discipline and engineering judgments. This was done to avoid security concerns, and to keep this report capable of being published in the public domain.

1. CC Efficiency

Efficiency is normally defined as output over input. CC Efficiency can be defined to be the ratio of mission effectiveness to the cost of the people required to man the system. The parameters for mission effectiveness are defined in Table 4 CCS MOMs. This form of cost is just one measure of input, and discussed in a later section. This results in the equation:

(1)

Where:

CCE – CC Efficiency (relative)

ME – Mission Effectiveness

Cost - Number of men required per shift

MOEs		MOPs		KPP	Threshold	Goal	Weight	Project Scoring Weight**	Rationale
Q	P	Q	P						
1.0 CC Efficiency *	Percent	CC Efficiency	Mission Effectiveness/Number of men per shift		50	90	N/A	N/A	
1.1 Mission Effectiveness*	Percent				86.9	96.5	0.7	N/A	Threshold and goals based on weighted roll-up of underlying MOMs
		1.1.1 Maintain contact	Percent maintained contacts	Y	80	99.9	0.25	0.319	1.1.1 through 1.1.3 were balanced to ensure that safety of ship would be the number 1 priority in mission effectiveness, maintaining contacts would be the second priority, as it is common to both safety of ship and mission success, and finally mission success is the third priority, as most of mission success is already covered in 1.1.1 and 1.1.2, leaving successful completion of assigned tasking. Though this might seem to be a low relative rating for mission success, Much of the mission success of a submarine is beyond the control of the submarine fleet. Historical statistical data, as well as results provided by tactical trainers can provide this type of data.
		1.1.2 Maintain Safety of Ship *	• Percent of correct decisions • Maintain Stand-off zone	Y	95	99	0.6	N/A	
		1.1.3 Mission Success*	Percent of mission success		78	93.4	0.15	N/A	Threshold and goals of mission success are based on the weighted roll-up of underlying MOMs
		1.1.3.1 Fusion Completeness of Comprehension	• Fusion Score of contributing sensors	Y	70	95	0.2	0.038	It was the team consensus that, although important, fusion was the least important contributor to ships safety
		1.1.3.2 TMA Correctness of Comprehension	• Accuracy	Y	50	90	0.5	0.096	It was the team consensus that TMA accuracy was the major contributor to mission success.
		1.1.3.3 Understanding			90	98	0.3	N/A	Although this is very important to mission success, this is really allocated to man as supervisor and, as such, is not conducive to CCS system directly, but

MOEs		MOPs		KPP	Threshold	Goal	Weight	Project Scoring Weight**	Rationale
Q	P	Q	P						
		Mission Requirements *							more to the full combat chain of command at a very high level of a system of system view. This is not included in the modeling, as how to quantify the "understanding mission requirements" was beyond the knowledge of the team members, and no references to this could be found.
1.2 Cost	Number of men required per shift	Number of men required per shift		Y	8	3	.3	0.547	The threshold was based on the current Virginia (VA) base-line, while the goal of three was based on the team feeling uncomfortable with going below two sensor operators and one CCS operator

Table 4 CCS MOMs

* MOMs that are not modeled in this project.

** Adjusted from recommended weights to compensate for those MOMs not modeled.

2. Mission Effectiveness

The established goal was to maximize system effectiveness, while reducing manpower. Mission Effectiveness is a function of:

- Mission success, as defined by the mission requirements,
- Ability to maintain safety of ship,
- Maintain contacts.

Mission success is partly related to completeness and correctness of understanding the tactical picture (environment) in addition to understanding the mission requirements. Mission success is measured by the completeness and correctness of comprehension (data fusion and TMA). The completeness of comprehension is the fusion score of the contributing sensors on a contact-by-contact basis. The correctness of comprehension is the accuracy of TMA on a contact-by-contact basis. Understanding mission requirements are the on-board command personnel's ability to comprehend the mission and translate the requirements into a mission execution plan. For the purposes of this project, the understanding of the mission requirements is assumed to be flawless.

The fusion score average describes the fusion comprehension metric.

(2)

Where:

CCF - Completeness of Comprehension (Fusion)

FSM - Fusion Score Mean

The correctness of the modeled comprehension in terms of TMA is composed of the fused range and bearing confidence averages. These components represent the accurate positional locations of the contacts that result in the performance of the tracker.

(3)

Where:

CCT - Correctness of Comprehension (TMA)

FBCM - Fused Bearing Confidence Mean

FRCM - Fused Range Confidence Mean

n – Number of contacts

Ship safety consists of personal practical safety, operational risk management and general safety standards [OPNAVINST, 2007]. Ship safety requires certain portions of the sensors to be functional, as well as the ability to fire weapons. Operational risk management is considered outside the project scope and is not considered. As defined in this project, maintenance of ship safety is the ability of the crew to make the appropriate (Percent of Correct) decisions by ensuring that navigation accounts for actions that avoid collisions and provides ample warning time to respond with evasive maneuvers.

Maintaining contacts is the ability of the system (which includes humans) to keep track of the environment and vessels in it. Vessels managed in the model consisted of warships, submarines, pleasure craft and merchant platforms. Contact Management is measured as the percent of maintained contacts.

The percent maintained contacts are defined as the ratio of the sum of stale contacts per sensor to the total number of contacts per sensor. Stale contacts are contacts that do not get processed by a sensor within a preset time due to operator workload. Further definition is available in the ExtendSim® model details section.

(4)

Where:

CM - Contacts Maintained (%)

3. Manpower Cost

Cost in this context is in terms of personnel per shift, and represents the number of personnel involved multiplied by the utilization coefficient. These factors characterize the use of the personnel in the TMA and the total pool, or the distribution of the workload.

(5)

Where:

$N_{Men\ TMA\ Pool}$ - Number TMA Pool

U_{TMA} - TMA Utilization

N_{Pool} - Number of Men Pool

U_{Pool} - Pool Utilization

VI MODEL DESIGN

During the modeling phase, a model of the CCS was developed to represent the data flow between the major CCS functions previously derived. This data flow model implemented a queuing theory model at each workstation to represent how well the model could keep up with incoming contacts, vice departing contacts.

From this "paper" model, a discrete-event simulation of the CCS was implemented using ExtendSim®. This executable simulation served as the basis for exploring the tradespace. It supported a sensitivity analysis and established an initial requirement baseline for key operational parameters (man power levels, machine strength, and the balance between man/machine interactions at the work stations).

In order to explore system feasibility, while characterizing system operation, it is common practice to model a process as a series of probabilistic decisions [National Research Council, 2007]. Thus, for this project, CCS was modeled as a series of functions, whose outputs were based on probabilistic outcomes, and were based on real world physics and known decision processes.

Figure 12 is an abstract visual aid that was constructed to assist in describing the approximate level of data within the engagement chain. This aid was constructed as a rough a rough correlation to the number of people required to sort through the data. The beige area shows the amount of raw data culled through, tapering off as higher level decisions are being made. Towards the right, more processed data outputs are required and less raw data. Currently, there are more people at the lower levels working on processing that data (with the aid of computers). Towards the right side of the chain, there are fewer people, but they are making higher-level command decisions. Because of the risk issues mentioned previously, it is anticipated that the decision-making command structure will not be removed. However, there is an underlying supposition that driving towards a higher level of automation in the detecting, identifying and tracking tasks will lower the manning requirements overall. In addition, this computational chain will lead into the decisions, where automation can be used to help put the SA picture together and provide suggestions on the TMA and Data Fusion (combination of contact information into knowledge of that contact). This automation allows the machine to suggest possible courses of action to the command personnel, such as how and when to steer the submarine, but leaving the decisions to the human.

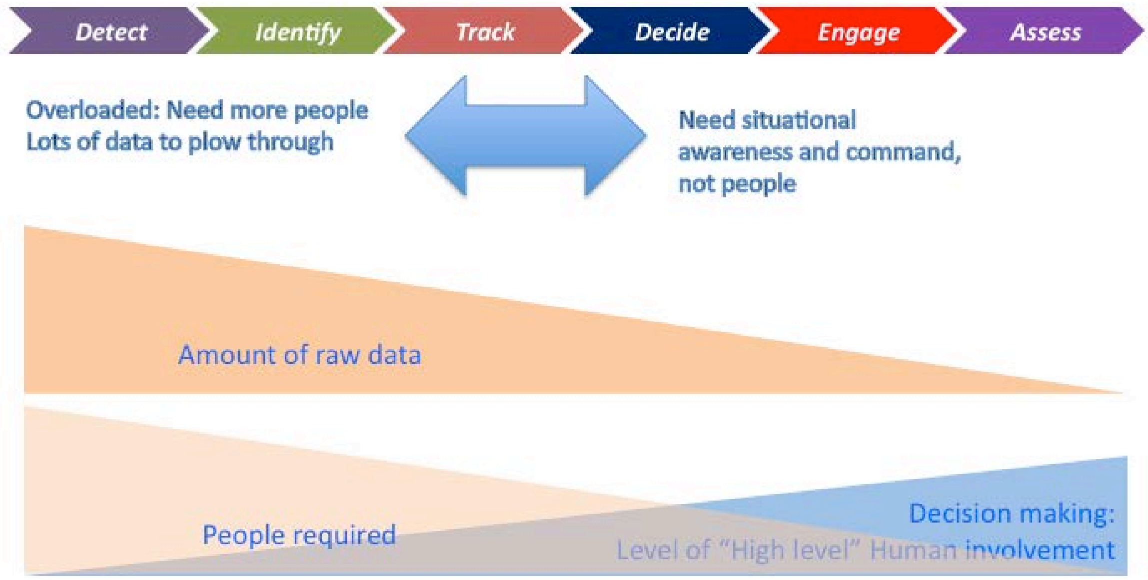


Figure 12 Data versus Human for Decision

The final architecture of the combat system (which includes man in the system) should be one that provides the best processing and the best decision-making. ***This balance is the crux of the model: to be able to input various levels of man and machine for certain tasks, and find empirically through simulation the most optimum levels.***

The model design, and hence, the high level architecture is based on the definition of SA: Perceive, comprehend and project [Endsley, 2006].

1. Perceive

In order to comprehend the environment, the first step is to sense the environment and assess those sensor outputs. For this study, the number of operators was not defined (although Figure 13 shows notional workstations). One of the desired outcomes is for the model to help determine the number of required operators. Although it is outside the scope of this project to define a physical architecture, one of the assumptions made was that each operator console was identical, and depending on the job performed, the operator simply runs a different piece of software. This is like a home computer. If you want to work with email, you activate an email client. If you wish to do graphic editing, you activate an appropriate application for that. It is assumed in this model that if the operator has to perform Broadband Gram (BBG) operations, he activates the BBG application or the imagery program if he needs to scan the periscope.

The actual algorithms that will be used to implement the perception engine are not modeled in this study. However, the probabilities of the various outcomes from that processing are recorded. The assumption is made that the operator will have a higher level of automation than is currently available in the Fleet. The operator is still primarily concerned with what is going on at the sensor level; that is, finding contacts and identifying them. The model is therefore designed to vary the level of automation, resulting in more or less human interaction, and more or less system effectiveness, yielding more or less cost.

Depending on the job and the cognitive loading involved, the operator may be able to handle multiple tasks. This is not unlike working on graphic editing, but occasionally checking email; both tasks are handled. This concept implies that operators can be pooled to accomplish more tasking, which allows for the possibility of the reduction of manpower.

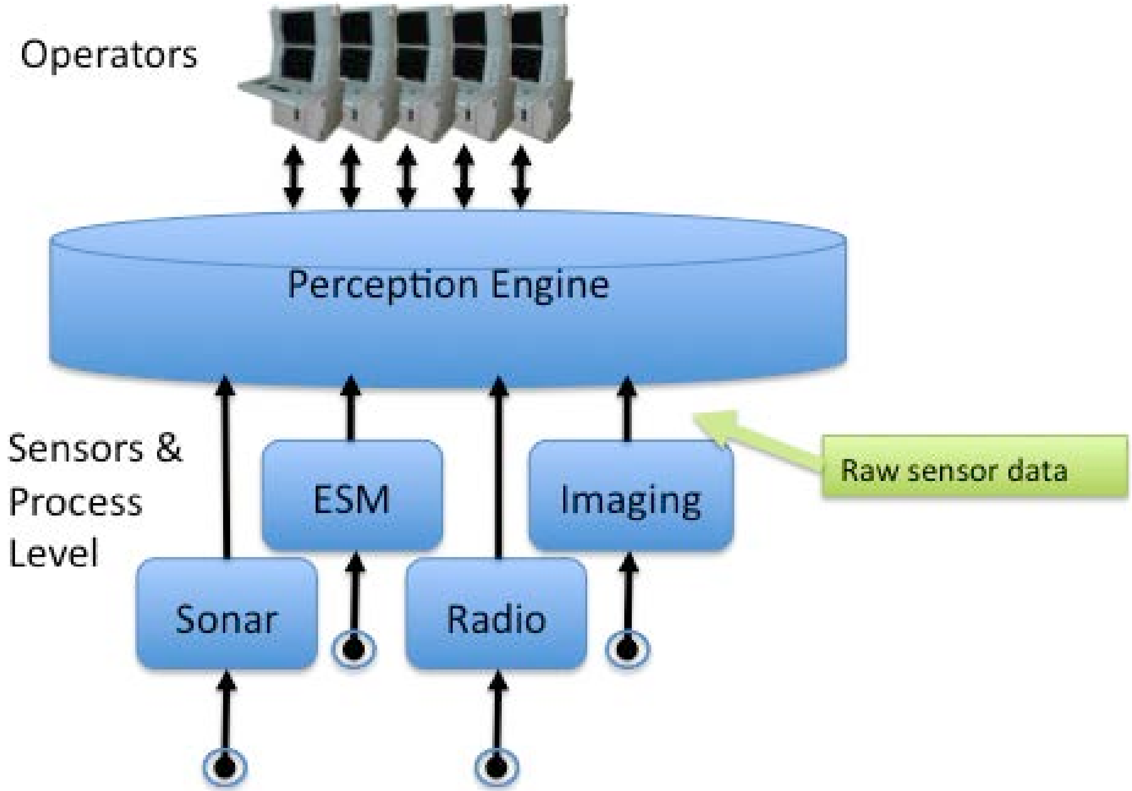


Figure 13: The Perception Engine

The perception engine works exclusively with sensor data, and not fused or combined information. The idea in the perception engine is that while the machine is working directly with the data, it is providing the man with advisory information at a sensor/contact level.

The human operator will be able to “drill” down to see the raw data if desired, but otherwise the machines are creating simply pieces of sensor dependent “chunks” of data on a contact. This term is merely being used conceptually to illustrate data flow, and still implies no particular implementation.

The perception engine performing these computational and advisory tasks is an enabler. The model was based on the premise that machines are able to better make recommendations that assist an operator than is possible today. The required machine effectiveness derived from the model may be used in the future as input requirements for a combat system developer.

a. *Contact Processing/Contact Assessment*

Contact processing and assessment were decomposed into two separate tasks. This allows for varying levels of automation. For example, the contact processing can be done more by machine, providing suggestions and direction to a human operator. The human operator acts as an assessor to the data the machine has derived for him. This allows more flexibility in the model without suggesting implementation.

2. Comprehend

The Comprehension Engine consists of those units that combine the sensor objects into a situational picture. It is designed to aid the OOD in putting together his mental model of the current situation.

The sensor outputs from the perception engine are used to generate trackers, perform TMA and begin fusing those outputs together. How accurately the individual contacts are understood (in range and bearing) allows them to be placed in the world model with the other contacts with some level of accuracy. Once the contacts are placed in the world, the submarine command can then develop the understanding (comprehension) of the situation they are in. Therefore, the accuracy of the data fusion implies greater probability of identification.

The Comprehension Engine, shown in Figure 14, likely has some sort of shared display unit in which the command team of the crew can visualize the situation, that is, where those contacts are placed in the world.

The team considered Air Traffic Control as a model for monitoring several contacts. It was rejected because on board a submarine the world is not transparent, as it is in aviation. Usually the contact cannot be seen, only heard. There are no IFF responses available as with aircraft, and thus location is only a guess. Therefore, the SA picture becomes more probabilistic than absolute. This train of thought came from discussions at the Naval War College [Bundy, 2010].

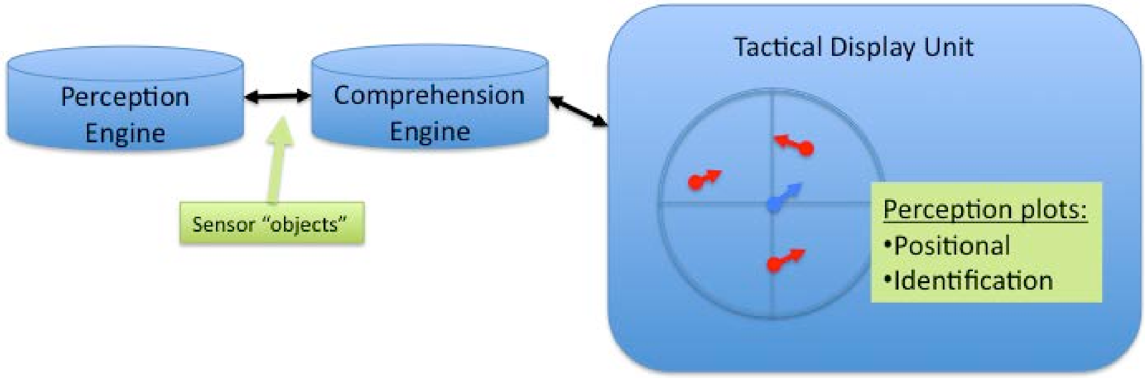
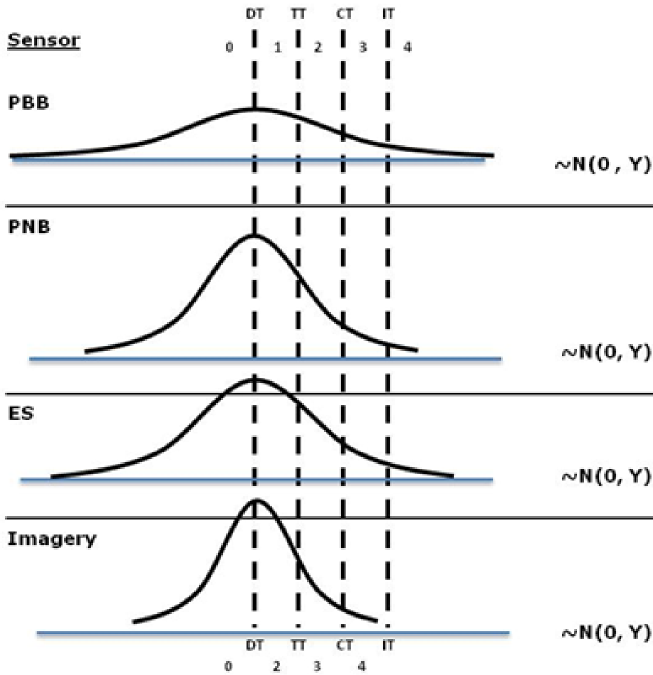


Figure 14 the Comprehension Engine

a. *TMA and Data Fusion*

Although the sensors themselves are outside the boundary of the model, a distribution of how each sensor acts was derived. These curves are estimated from interviews with SMEs and the experience of the team. They are shown in Figure 15, and represent the level of output energy of the contact above the background noise (that is, a recognition differential). The leftmost vertical (dashed) line is the cut-off between detectable and not detectable. Nothing to the left is detected. Everything to the right is detected, and there may be enough energy to place that contact in a higher category (whether or not the contact can be tracked, classified or identified).



Sensor	Possible Outcomes	Target Range Confidence	Target Bearing Confidence
PBB	0	0	0
	1	0	0.8
	2	0.5	0.9
PNB	0	0	0
	1	0	0.8
	2	0.5	0.9
	3	0.5	1
ES	0	0	0
	1	0	0.2
	3	0.6	0.8
Imagery	0	0	0
	2	0.6	0.9
	3	0.9	1
	4	0.9	1
AIS	0	0	0
	4	1	1

Figure 15 Sensor Outputs and Fusion / TMA outputs

The "fused" location (range and bearing) certainty is the maximum accuracy of both range and bearing of all the sensors. This table provides confidence estimates derived by the team with inputs derived from discussions with Mr. Williamson [Williamson, 2010] and team experience. These values can be verified and modified in the future.

The current fleet guidance is to perform TMA on all contacts. In heavy contact areas, this is not always possible as it is a time consuming task, and must be continuously updated depending on ownship and contact motion. Therefore, the crew typically prioritizes based on what is most important to them at the time. This is governed by range (close in contacts are high priority to avoid an accident) and type (certain contacts are more important, such as warships). The concept of range and criticality became important to the model as the man-machine tradespace was developed.

Data Fusion is the process of combining the sensor outputs from all available sensors into a single target vector on a per contact basis. Washburn's work described the TMA process of analyzing the contact localization and movement estimation based on the sensor bearing output [Washburn, 2010]. The system goal is to improve the accuracy of the bearing measurements in an attempt to reduce the error ellipse associated with the bearing data. Improved sensor accuracy, or the use of more sensors, will improve the contact bearing estimates which will improve the results of TMA.

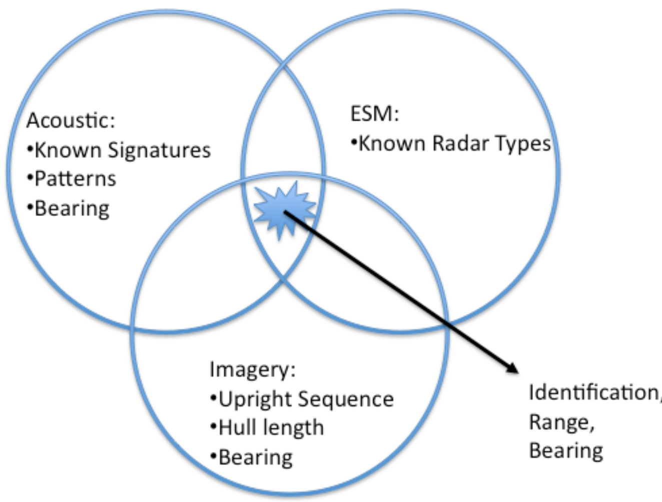


Figure 16 Probabilistic Data Fusion

As with the sensor outputs, the interest was not so much in the actual details, but rather the confidence of how well the fusion was performed. To validate our methodology of deriving the fusion and TMA output confidence, we considered the set of performance measures for the fusion itself. This list is provided by James Llinas [Llinas, 2009]:

- Detection probability – probability of detecting entities as a function of range, signal-to-noise ratio, and so on
- False alarm rate – rate at which noisy or spurious signals are incorrectly identified as valid targets
- Location estimate accuracy – the accuracy with which the position of an entity is determined

- Identification probability – probability of correctly identifying an entity as a target
- Identification range – the range between a sensing system and target at which the probability of correct identification exceeds an established threshold
- Time from transmission to detect – time delay between a signal emitted by a target (or by an active sensor) and the detection by a fusion system
- Target classification accuracy – ability of a sensor suite and fusion system to correctly identify a target as a member of a general (or particular) class or category

While this list is generated for the data fusion itself, this study is at a higher level for some of these measures. That is, the concern is with the confidence of the output, not the output itself. They are not used directly, but rather indirectly in the form of validating the contact data.

The outcome of data fusion and TMA is an estimate of location (and identification) of that contact. The better the information on that contact implies a better location, in terms of range and bearing from the submarine. What is needed for the model is not the actual location, but rather the confidence of the location. Therefore, the possible sensor outcomes (0-4) are correlated to a location confidence.

The location estimate accuracy, classification accuracy, and identification probability were included in the probability output table. This location estimate includes two parts: bearing and range of the contact relative to ownship position. The kinematics of ownship-to-contact relationship is accounted for in the variability in the contact distribution in terms of differing speeds, aspects and depth.

Although time is included in the model, it is used to handle the lifespan of each contact (how long they are within detection range). Time is also used to for operator service times so that operator workload can be observed.

b. *Trackers*

Trackers are generally used more in the area of perception to mark where the operator should be looking. In this project, the team elected to locate them in the comprehend engine. This is not to imply implementation, but rather to allow that sometime in the future, the machine may be able to track across sensor type, to better comprehend the situation. This implies a higher level of automation, and is akin to data fusion, which belongs in the comprehension engine.

3. Projection

The last part of the SA definition is "project" [Endsley, 2006]. In this case, that means generating appropriate recommendations for action based on the current situation. For example, if a contact gets too close, the submarine command might decide to maneuver around it or fire weapons. Each decision has risk and ramifications, and each depends on the mission requirements. To make the decision to maneuver, for example, requires an understanding of the contacts in the immediate area and the ability to project forward in time to predict position and avoid a collision.

There are many possible ways of handling these situational projections. Cues can be taken from Sheridan in his levels of automation as shown in Table 5 [Sheridan, 2002].

Automation Level	Description
1	Automation offers no aid; human in complete control
2	Automation suggests multiple alternatives; filters and highlights what it considers to be the best alternatives
3	Automation selects an alternative; one set of information, or a way to do the task and suggests it to the person
4	Automation carries out the action if the person approves
5	Automation provides the person with limited time to veto the action before it carries out the action.
6	Automation carries out an action then informs the person
7	Automation carries out an action and informs the person only if asked
8	Automation selects method, executes task, and ignores the human (i.e., the human has no veto power and is not informed).

Table 5 Automation Level Descriptions [Sheridan, 2002]

As mentioned above, the risk is too great to leave the actual performing of action to a machine unless a high level of trust has been developed. Developing this level of trust in a complex system is discussed in an article by Philip Chapel of the Australian Department of Defense, in which a system can be used to alert the operator to the presence of mine-like objects and other significant features [Chapel, 2010].

> "A useful rule-of-thumb is that, for an automated detection system to be trusted, the expectation of detecting a genuine target must be at least ten times the expectation of encountering a false alarm"

Chapel goes on to describe two scenarios that may cause the system not to be used. First, the human operators outperform the machine, making the machine unreliable. Second, the operators are unreliable, especially when the detection process is too difficult. The expectation is to improve machine decision making processes eventually, but in the shorter term, it might not be possible. To some degree, the surface ship community has been able to do this. The surface sonar community is more aware of the environment (for example, they have constant weather, Global Positioning, RADAR and AIS feedback). They do not have the disadvantage of relying on passive sensors and historical databases to define the environment as does the submerged submarine.

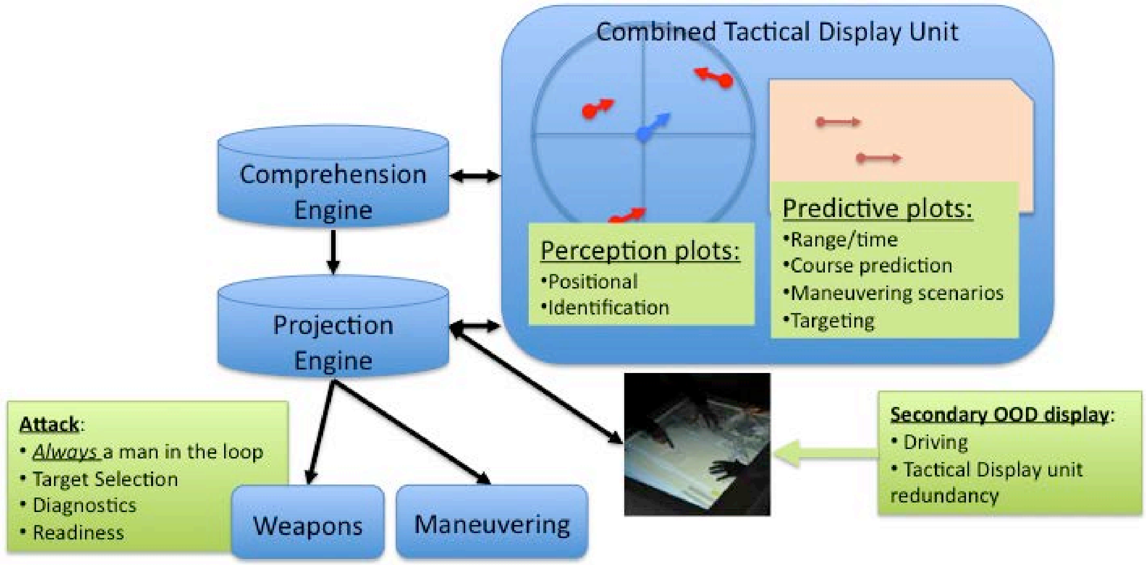


Figure 17 The Projection Engine

Because the actual action to be taken requires understanding of the particular mission requirements, it was decided not to simulate the action. Taking correct action depends on how well the comprehension is developed. It is assumed that the best possible situational picture will enable the submarine captain to make the correct decision (see Appendix B). Therefore, in the model developed, the actual "act" is left to the human. This would equate to (depending on the action) either level 3 or 4 of Sheridan's automation levels.

Some of the SA development (prediction) can be automated. Collisions can be projected and avoided, as well as warnings of increased probability of ownship detection. However, much cannot be automated. For example, some predictions might depend on understanding of wartime tactics. Therefore, the machines are allowed to aid in the decision making process (taking on an advisory role), but a human, who can not only comprehend the current situation, but also make decisions based on his needs, must make the ultimate decision. To summarize, “Accurate choice will depend on good SA, but choice is not the same as SA [Parasuraman, et al., 2008]”. Therefore, this is left as a separate step in the model, the last step before assessment and is labeled as “Act”.

VII MODELING AND SIMULATION

A. APPROACH

As described previously in the Systems Engineering process, there are three models developed for this project; architectural, cost and ExtendSim®. These are described in the following sections.

B. MODEL BLOCK DIAGRAM

The block diagram of the model is illustrated in Figure 18. It is based on the capabilities shown in Figure 11. The following sections discuss the major features of this model.

1. Contacts and Sensors

The actual contact details and characterization are outside the boundary of the model, yet they are required to perform the processing. The contacts in the model are:

- Warships,
- Submarines,
- Pleasure craft,
- Merchants.

The modeled sensor outcomes were probabilistically generalized, as it is beyond the scope of this study to directly model the performance of the sensors. Therefore, the sensors in the model output the probabilistic outcomes as shown in Table 6. In the real sensor environment, these are related to the contact SNR, as seen at the sensor's receiver. These outcomes are supplied to CCS, where further processing is applied to support the engagement chain.

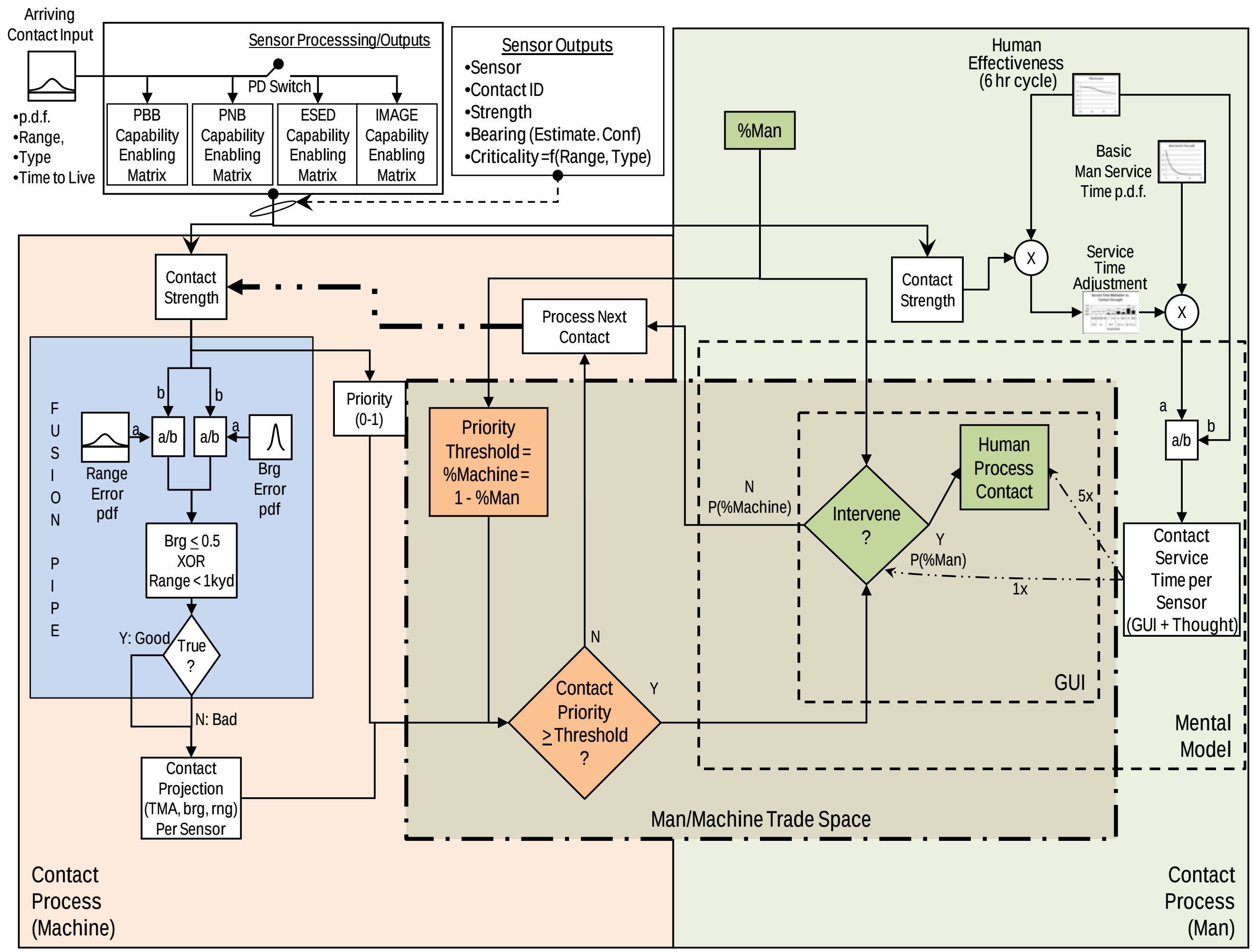


Figure 18 Model Block Diagram with Man-Machine Tradespace Highlighted

Outcome	Category	Description
0	No Detect	The system never knew the contact was present
1	Detected	The system knew the contact was there, but it was not clear what the contact was, and the location is not clear.
2	Trackable	The system found the contact, and was able to place an automated tracker on it. The trackers are not perfect, and may require manual updating in some circumstances such as the submarine going through a turn.
3	Classifiable	Not only does the system know where it is, but also there is enough information available to be able to tell what type contact it is.
4	Identifiable	Not only does the system know what type of contact it is, but also it knows exactly which vessel/hull name it is. This implies there is some known information on that vessel. For example, the crew can see via periscope imagery that the sighted contact is an aircraft carrier of a given country. There is intelligence, or they can read the number off the front of the contact, that it is that exact aircraft carrier.

Table 6 Sensor Outcomes

2. The Man-Machine Tradespace

Figure 18 illustrates the tradespace in the area outlined and marked Man/Machine Trade-space. This tradespace consists of:

- Percent man versus machine used at each workstation,
- Number of men available to perform a function,

- Threshold used to determine if a contact has sufficient priority to engage “man as operator”,
- Probability that the man will accept the machine’s recommendation or a more in depth review of the recommendation.

The overall effectiveness of the system is driven by the combined effectiveness of man and machine over time, coupled with the percent man or machine at each workstation supporting a particular capability of the engagement chain. The model design permits modifying the balance between man and machine at any CCS workstation. In the model, this balance is maintained by the priority threshold. If a contact priority exceeds the priority threshold, that contact is presented to the operator with amplifying information, track history and track projection. Otherwise, the contact is hidden from the operator except as a process data output. If the operator is presented with the contact, the operator can either accept the contact or decide to validate the contact. The priority threshold can be thought of as a “machine sensitivity knob”, which could easily be built into an implementation of CCS. The machine sensitivity knob capability represents one of the major new architectural features of the proposed construct. One of the key attributes of this tradespace detail is that, as trust in the machine as operator (automation) is increased, the percent man can be decreased (percent machine increased).

The operational parameter that controls this tradespace is Percent Man as indicated by the green box in the top center of Figure 18. The Percent Machine is calculated as (1- Percent Man). The Priority Threshold is simply set to the Percent Machine used in the system.

In addition to the machine sensitivity feature presented above, the second major architectural feature of this construct is the fusion pipeline shown in light blue in Figure 18. This pipeline is where each sensor presents its contact to the CCS, and where the CCS returns fused contact information to the sensors. If a contact exits in the Fusion Pipe with a priority lower than the priority threshold, then it is simply handled by the machine and the next contact is processed.

From a roles and responsibilities perspective, this mechanism assumes that the machine is acting in the operator role, providing advisory information to the human. If the human rejects the advice, then he is forced to spend more time either processing it himself or providing guidance to the machine. The human can become overloaded. If this happens, the threshold should be adjusted such that the machine is handling a higher percentage of the contacts.

3. Contact Prioritization

One important part of the sensor outputs is a contact strength (level of detection), which influences the fusion and TMA. The blue fusion pipe box is already described above in the Fusion / TMA output table. “Criticality” is a term used to identify how important a contact was to the model, so prioritization of contacts can take place. For simplicity, the team agreed that ultimately the criticality of each contact is dependent on type: submarine, warship, merchant or pleasure craft. A criticality value is assigned to each contact type based on how important the contact is to the safety and mission of the submarine. The priority of a contact is calculated as a function of the normalized range, speed, direction and criticality of that contact. For example, a distant fishing submarine is not as critical as a nearby warship. As the contact approaches ownship, the priority and awareness increase, as illustrated in Figure 19. Regular awareness is shown in green, elevated awareness is shown in yellow, high awareness is shown in gray and the exclusion zone is shown in orange.

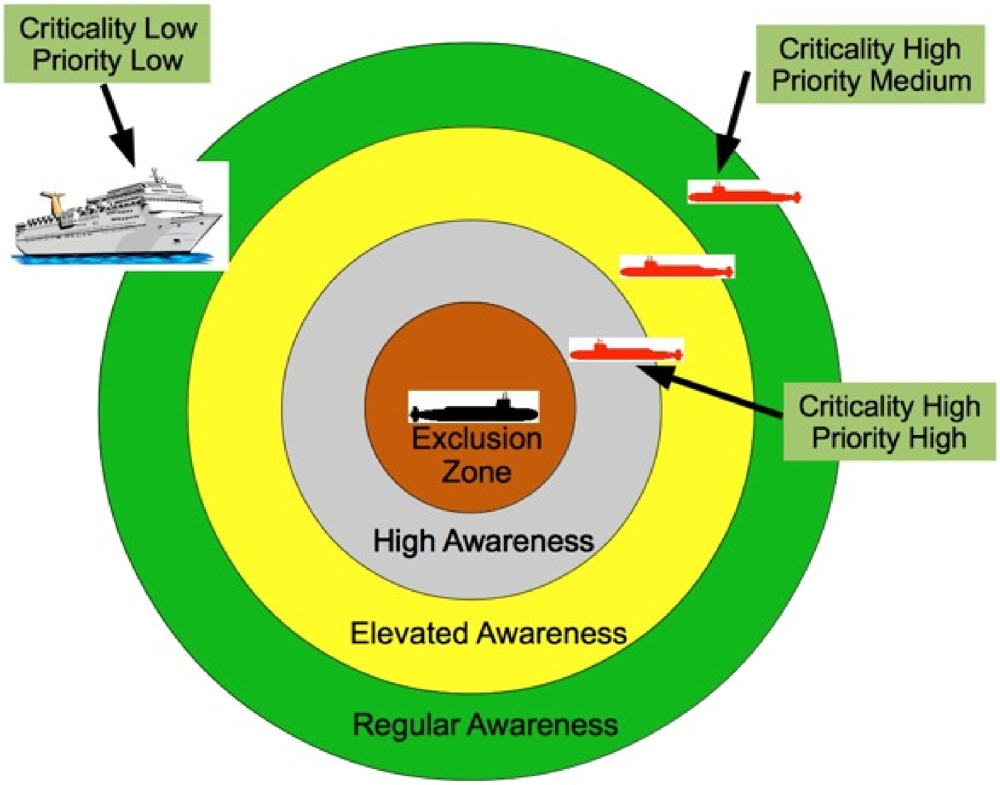


Figure 19 Contact Prioritization Illustration

4. Human Effectiveness

For the model, it was assumed that the processing power will be available to process as many contacts as are needed. It is also assumed that the costs of additional processing power will be negligible in the future based on the historical trend of decreased hardware costs, with increased performance. Humans on the other hand, have a definite processing time, which is defined by a 6-hour shift cycle. The human has a basic service time that is adjusted by the time in his shift. Each sensor type has its own basic processing cycle time.

This model does in fact change the operators' CONOPS. The more machine utilization (lowering the % Man), the human becomes a "supervisor" whose job it is to accept or reject the machine's recommendations.

This, in effect, changes the role of the human in the system. The automation should be better at low level calculations and repetitive tasks (the menial and error-prone parts). Therefore, it is assumed that the automation would start there, and as it becomes better could take over more of the human performed low-level jobs.

5. Pooled Resources

Another key aspect of the model is the concept of pooled resources. Rather than having an individual operator for each sensor, the model relies on a pool of qualified operators that can be assigned to various process tasks. This "pool" allows for maximum utilization of fewer operators to perform the same function as many specialized operators. In the model, there are two resource pools, one serving the TMA function and the other performing detect and identify functions for all sensors.

6. Human System Interface

It is also assumed that the human interface is advanced enough such that all the information the operator requires to make a good decision is organized in a way that it is readily available.

Human System Integration (HSI) is accounted for in the model. The Contact Service time per Sensor portion (right side, in the middle of Figure 18) considers this, and is adjusted. It could be said that HSI actually increases or decreases human effectiveness (upper right corner of Figure 18). Also, this mechanism was used to generate a varying human effectiveness based on circadian rhythms in

Figure 20, also supported by the model [Duplessis et. al, 2007].

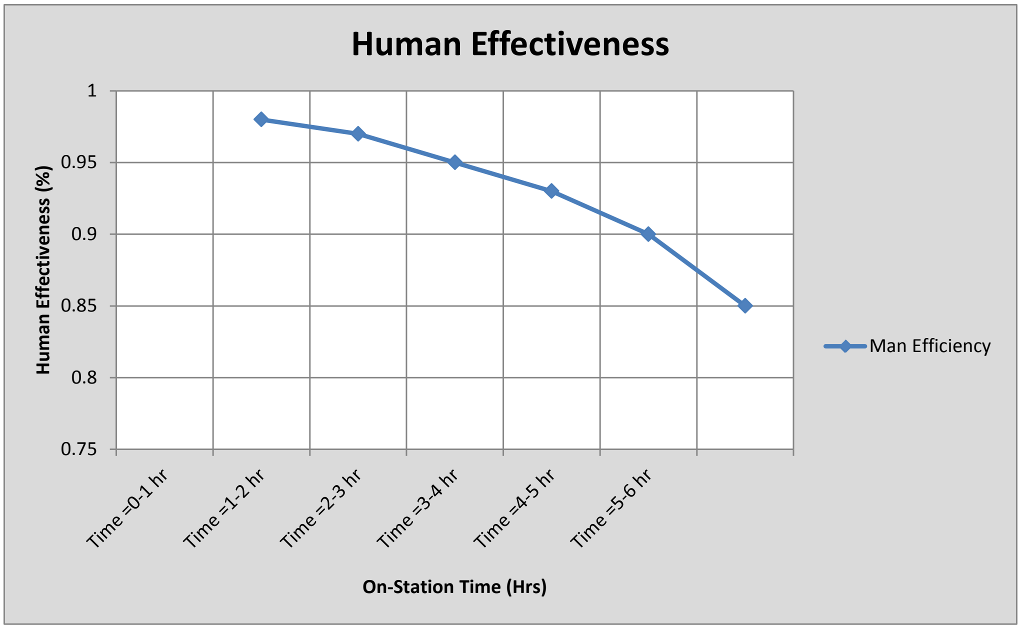


Figure 20 Human Effectiveness

7. Operator Load and CONEMP

The level of machine utilization and effectiveness was allowed to vary, thereby changing the model outcomes. The more automation was utilized and the higher the effectiveness of that automation resulted in outcomes greater or less than that of a near wholly human operated submarine combat system.

One important aspect not considered in the model is operator complacency. Since the operator is now required to perform more (albeit a higher level) jobs, and if he accepts most of the machine recommendations without checking the data, he may lose effectiveness. The hope is that the higher level of data and indeed responsibility of the operator should keep him closer to the optimal range of attention (arousal). "Moray and Inagaki (2000) suggested that the attention allocation strategy could be rational and, furthermore, that complacency should be inferred only if the rate of monitoring was below that of an "optimal" observer who was required to attend to many sources of information (the automated task being one such source)" [Parasuraman, et al., 2008]. Therefore, the idea of giving him more tasks is not just for purposes of lowering manpower, but rather it is required in an alternate CONEMP in order to maintain vigilance. “Moray and Inagaki suggested that a human operator who monitored automation at a lesser rate than the optimal Nyquist frequency was complacent and the one who monitored at a greater rate was skeptical, whereas the one who monitored at the optimal rate was eutectic (or well calibrated)” [Parasuraman, et al., 2008].

This concept is reinforced by the Yerkes-Dodson law, in which it is seen that if the operator is not engaged enough, his level of performance is lower, as well as if he is too engaged. A variation of the Yerkes-Dodson law is depicted in Figure 21.

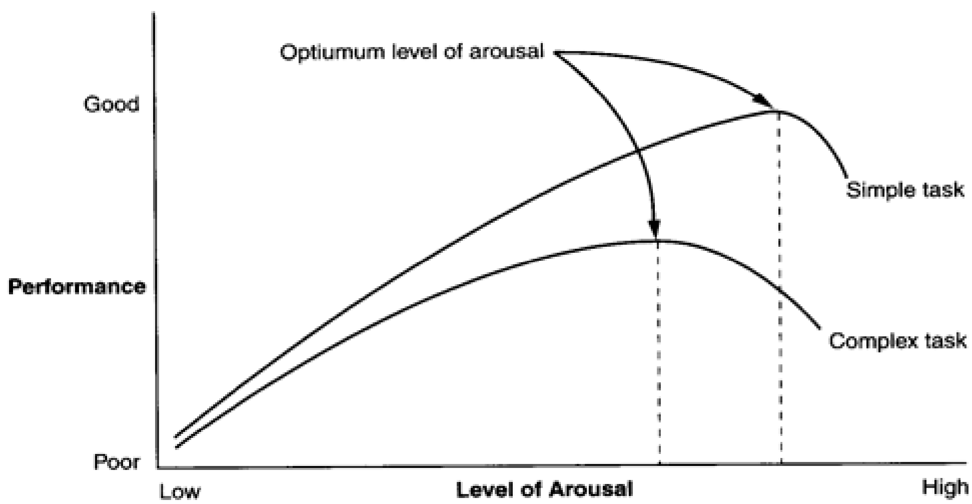


Figure 21 Arousal Level [Schmidt, 2010]

The operator will begin to shed tasks in times of heavier stress (more contacts, mission area, etc.). This is the time where it is more important than ever to have automation (that the operator can trust) in the system to assist him.

Too much trust in the automation implies an increase in complacency. The human becomes reliant on the machine, and essentially bored. Therefore, in order to maintain vigilance (lower complacency), the answer is not to simply lower the workload. Man must be kept “in the loop”, that is, engaged. In order to accomplish this, more reliance on automation is required, but also the human must have more tasks to accomplish. The operator is no longer bored by his job, but rather can accomplish more when aided by automation. This has the effect of raising the operator to the supervisor level, and results in his processing machine advisories from several different sources.

Verification of combined machine outputs is not validated by looking at the raw data, but rather confirmed or denied by use of other systems. For example, if a contact is detected by a system, the system automatically initializes trackers and begins the process of classification and identification. Today, the human checks the inputs to this automation. The human is now forced to reconstruct the same process the automation has already completed. Rather, if two separate systems can come to a similar conclusion, then the outputs are reinforced without the need for a human to examine the raw data. As an example, the sonar operator is elevated from looking specifically at the towed array data to looking at the automated outputs from all the sensors combined and verified with multiple automated methods. This effectively eliminates operators of other arrays.

C. COST MODEL

The following assumptions were made pertaining to cost data in support of the USN's wide initiative to reduce TOC:

- Applicable only to Submarine personnel,
- Addresses Combat Control operations,
- Does not incorporate effects due to personnel reduction outside combat control,
    - Crew’s mess
    - Damage Control
    - General ship maintenance
- No consequence will be incurred by reducing personnel.

The thought process is that if manning can be reduced on a platform as a result of applying automation to human intensive processes, then actual cost reduction can be realized by the annual labor rate associated with the elimination of the manual tasks. Aside from the reduction of actual labor cost by replacing a human operated task with a machine automated task, RTOC will be seen at the operating level of the platform. This includes, but is not limited to, the amount of provisions (food), berthing, linen or the basic necessitates needed per sailor. Indirect areas that might contribute to RTOC based on reduced manning include the amount of oxygen the air handling system will need to generate, the amount of water purified and the amount of waste produced. On an even more remote level, the administration of sailors, such as accountability, medical care or liability (annual or sick leave) could certainly contribute to lowering the TOC of operation of a submarine.

Total Ownership Cost (TOC) is defined per platform as in Allison [Allison, 2000]:

(6)

Direct Unit Cost (DUC) and Indirect Cost (IC) are where the realization or reductions can be seen. The Direct Intermediate Maintenance Cost (DIC) and Direct Depot Maintenance Cost (DDC) are assumed not affected by the analysis put forth from SCSEP and are therefore outside the scope of this project. To reduce TOC for the future VA fleet (and others) with respect to the Combat System, equation (6) can be modified to:

(7)

Where:

$RTOC_{VA}$ – VA Fleet RTOC (projected at 18 platforms), Future VA $Fleet_{2020}$ – Quantity of VA submarines projected in 2020,

$RTOC_{Cost\ Savings\ per\ Combat\ System}$ – Cost Savings per Combat System.

Table 7 shows the number if enlisted personnel on board a VA Class submarine. These personnel and rates were selected to show the impact of reduced manning for one submarine. The enlisted personnel were determined by analysis of the Automated Readiness Information System (ARIS) Rating Control Numbers (RCNs) for the USS New Hampshire [Devers, 2011].

Enlisted Combat System Personnel					
	Sonar Technician Submarine (STS)	Fire Control Technicians (FT)	Torpedo (TM)	Navigation/ Communication Electronics Technicians (ET)	Radioman
Senior	8	3	3	4	3
Junior	9	4	4	5	5
	17	7	7	9	8

Table 7 Summary of USS New Hampshire Enlisted Personnel

By coupling the data shown in Table 7 and the results that are output by the SCSEP model (see section VII), the number of sailors reduced on a VA platform can be quantified into dollars.

Table 8 is derived from raw VAMOSC-ISR Data, converted using current inflation indices and illustrates the overall cost for enlisted sailors projected for Fiscal Years (FY) 2011 thru 2020. [VAMOSC 2010] The ten year projected cost per person per platform is used to illustrate the overall magnitude of the cost reduction. For example, if the reduction is in terms of 4 sailors, over the course of anticipated ten years the savings would be $4,141,749. Projecting this platform savings to the fleet of eighteen (18) platforms would amount to a RTOC of $74,551,489.

		Number of Enlisted Sailors							
FY	Index	1	2	3	4	5	6	7	25
2011	1.0000	$92,757	$185,515	$278,272	$371,029	$463,787	$556,544	$649,301	$2,318,925
2012	1.0155	$94,195	$188,390	$282,586	$376,781	$470,976	$565,171	$659,367	$2,354,880
2013	1.0371	$96,199	$192,398	$288,596	$384,795	$480,994	$577,193	$673,392	$2,404,970
2014	1.0649	$98,774	$197,548	$296,323	$395,097	$493,871	$592,645	$691,419	$2,469,354
2015	1.0947	$101,540	$203,080	$304,620	$406,159	$507,699	$609,239	$710,779	$2,538,496
2016	1.1253	$104,383	$208,766	$313,149	$417,532	$521,915	$626,298	$730,681	$2,609,574
2017	1.1568	$107,306	$214,611	$321,917	$429,223	$536,528	$643,834	$751,140	$2,682,642
2018	1.1892	$110,310	$220,621	$330,931	$441,241	$551,551	$661,862	$772,172	$2,757,756
2019	1.2225	$113,399	$226,798	$340,197	$453,596	$566,995	$680,394	$793,793	$2,834,973
2020	1.2568	$116,574	$233,148	$349,722	$466,296	$582,871	$699,445	$816,019	$2,914,353
	Totals	$1,035,437	$2,070,875	$3,106,312	$4,141,749	$5,177,187	$6,212,624	$7,248,061	$25,885,926

Table 8 RTOC of Personnel Labor Summary

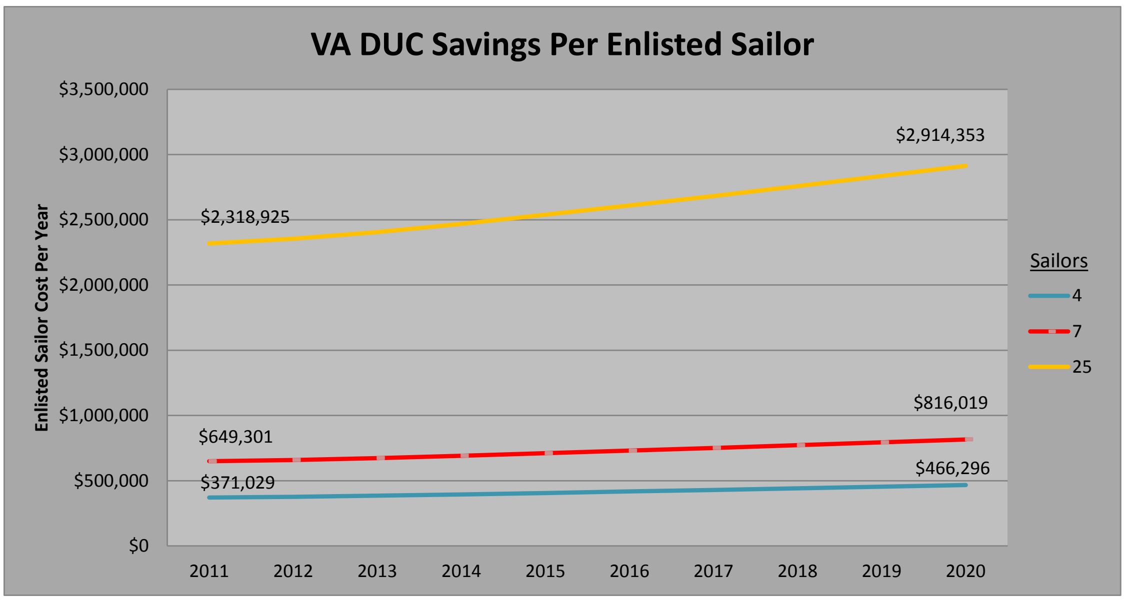


Figure 22: VA DUC Savings Per Enlisted Sailor Reduction

Figure 22 uses the cost data in Table 8 to show the overall potential RTOC for VA Class over a ten year period. This savings only applies to personnel labor costs. The net cost reduction of the entire platform is out of scope of this project. However, numerous studies have been conducted that have addressed the net reduction in manning. One such study specifically focused on cost model for United States Nuclear Submarines [Allison, 2000]. Coupling this with other studies and this project's results could be used to spawn a study on net RTOC cost figures.

D. EXTENDSIM® MODEL DETAILS

1. Approach

A discrete-event simulation based on the architectural model shown in Figure 18, above, was developed using ExtendSim7®. The design of the model, as well as key assumptions and parameters, are discussed in the following paragraphs.

The simulations were based on the following concepts and derived from multiple Design of Experiment (DOE) sources:

- Input factors: These are also called independent variables. These are the inputs that the designer has control over.
- Noise factors: These are sources of uncontrolled variations in a process. These have been modeled as probability functions or in one case a periodic function of time.
- Output factors: These are also called dependent variables. For any process, there can be many output factors. It is best practice to only be concerned with those that relate to the outcome of the process that are system KPPs.

For each sensor in the contact processing there are three input factors that are modeled as operational parameters: (a) percent man involvement, (b) the number of operators available, and (c) the effectiveness of the machine relative to man's top effectiveness.

In addition to these input factors, there are five noise factors in the basic model. These noise factors include: (a) the Poisson arrival rate for each type of contact, (b) life time for each arriving contact, (c) the signal level for each arriving contact, (d) the exponentially distributed service time for man as backup operator or supervisor for each contact, and (e) human effectiveness at any given time. It is assumed that once each of the sensors detects a given contact, its signal level is constant. Holding the signal level constant was done for simplicity. The overall effect of signal fading is incorporated into the probability distributions related to sensor capabilities and the TMA and Accuracy measures.

Table 9 shows a complete list of the input and noise factors that were implemented to support the simulation runs.

Unless otherwise specified, the values used for the model parameters described below were all assumed based on the best judgment of project members' in our respective discipline and engineering judgments.

Input Factors	
% Man BBG Process	
% Man NBG Process	
% Man Visual Process	
% Man ES Process	
% Man Update Tracker Process	
% Man TMA Process	
# Men TMA	
# Men Pool	
Machine Effectiveness	
Noise Factors	
Submarine	Poisson arrival rate
Warship	Poisson arrival rate
Merchant	Poisson arrival rate
Pleasure Craft	Poisson arrival rate
Contact life time	Uniform distribution
Human effectiveness	Periodic function of time
Human contact service time	Exponential distribution
Contact signal strength	Based on zero mean normal distributions, and a function of sensor

Table 9 ExtendSim® Input and Noise Factors

The output factors measured are the four simulation related CCS KPPs discussed above:

- Percent maintained contacts,
- Fusion score,
- Accuracy measure, and
- Number of men used.

2. Contacts Attributes.

In the model, contacts are generated randomly, and then each contact is passed to a detection and identification process for NBG, BBG, Imagery, ES and AIS sensors. The contacts are then assigned a status of non-detected, detected, trackable, classifiable or identifiable. After being processed for detection and identification the contacts get fused, their trackers are maintained continuously, for the lifespan of the contact and finally TMA is performed. At each process in the model, data is recorded and sent to an output Excel file for post analysis.

The four contact types (submarines, warships, merchant ships, and pleasure craft) are generated via a Poisson distribution. The inter-arrival times that were selected were based on a worst case surface transit through the Straits of Gibraltar. Calculation of the contact density over a period of several hours was performed using VT Explorer® AIS software. The counting included the binning of the contacts into the categories of warship, merchant and pleasure craft. The mean time between arrivals is shown below for each contact type.

Mean Interarrival Times (minutes)			
Submarine	Warship	Merchant	Pleasure
60	60	5.71	36

Table 10 Contact Arrival Rates

Once contacts are generated, they are assigned various attributes, which are utilized throughout the model. Two of the attributes are visual and acoustic strength. These attributes are compared against given thresholds to determine the percentage of contacts that are non-detectable, detectable, trackable, identifiable or classifiable. The thresholds were based on achieving the probability distributions for each sensor type shown in Table 11. These probability distribution functions are derived from SME interviews and team experience. The visual and acoustic strength are later multiplied by the man and/or machine effectiveness, which results in a shift of those probability distributions. The man's effectiveness from

Figure 20 varies with time from a minimum of 0.69 to a max of 1.0 with an average of 0.81 [Duplessis, et al., 2007]. As man's effectiveness decreases, he makes more mistakes and takes more time to accomplish tasks. The machine effectiveness was varied as one of the input variables with a minimum of 0.345 and a max of 2, which is twice the range of the man's effectiveness.

Another attribute that is assigned to each contact is lifespan. The lifespan is intended to simulate the amount of time that each contact is within sensor range. The lifespan for all contacts was assumed to be a uniform distribution between 10 and 60 minutes. If contacts were not detected before they reached their lifespan, they were assigned a status of non-detected by each sensor. The lifespan was also utilized during the update tracker portion of the model. Contacts were cycled through the update tracker process continuously until their lifespan was reached.

	Probability Distributions (%)				
	Non-Detectable	Detectable	Trackable	Classifiable	Identifiable
BBG	10	30	60		
NBG	10	30	20	40	
ES	20	30		50	
Imaging	10		50	20	20
AIS Merchants	10				90
AIS Warships	90				10
AIS Sub/Pleasure	100				0

Table 11 Sensor Probability Distributions

One feature included to model the effects of an overloaded operator is a measure of how many contacts wait an excessive amount of time before they are processed by a person. Prior to each detection process, the model utilizes a queue to simulate contacts that have not been detected because they are waiting for the operator to have time to process them. For the NBG, BBG, and imagery detection processes, if contacts stayed in that queue for greater than 5 minutes, they were declared stale targets and assigned a non-detected status.

3. Human Effectiveness

Another key factor used by the model is the basic service time needed to perform each task. Table 12 shows the service times derived from SME interviews and team experience that were utilized in the simulation. The manual service time is assumed to be the time it takes a man to perform a task without assistance from a machine. As discussed in the modeling and simulation approach section, when the percent machine is increased, the man's role becomes more of an advisory role and therefore the basic service times utilized for that process were assumed to be 20% of the values shown in Table 12.

	Basic Manual Service Time (seconds)				
	Non-Detectable	Detectable	Trackable	Classifiable	Identifiable
BBG	0	30	67.5		
NBG	0	400	500	255	
ES	0	4		60	
Imaging	0		10	12	63
Update Trackers	0		30	30	30
TMA	0		300	300	300

Table 12 Basic Service Times

4. Contact Prioritization

Another attribute assigned to each contact is level of criticality. The level of criticality is based on the type of contact. Submarines and warships were assigned a value of 1, merchant ships were assigned a value of 0.5 and pleasure crafts were assigned a value of 0.1. The criticality was then multiplied by a range factor to determine an overall contact priority. The result is that closer contacts with higher criticality level are assigned a high level of priority. Likewise the lower the criticality level and the farther away the contact is, the lower its priority level.

5. Contact Fusion

The model simulates contact fusion by comparing the status of each contact after they have been processed by their respective sensors in accordance with the values shown in Table 13. Sensor contribution is based on how much a given sensor, independent of other factors, contributes to fusion. The capability contribution shows the strength of the fusion contribution, with tracking contributing 90% of the fusion, tracking and classification contributing 95%, and tracking, classification, and identification contributing 100%. For example, a contact that is identifiable by the NBG sensor would be assigned an NBG value of 0.4. These scores are then used to calculate a fusion score. The maximum sensor fusion values for each sensor are added together and divided by the maximum possible fusion score (0.955) to arrive at the fusion score for each contact.

		Capability Contribution				
Sensor		**Track**	**Classify**	**Identify**		
	Sensor Contribution	0.9	0.95	1		
AIS	0.15			0.15	0.15	Maximum Score
Imaging	0.15	0.135	0.1425	0.15	0.15	
ES	0.1		0.095		0.095	
NBG	0.4	0.36	0.38		0.38	
BBG	0.2	0.18			0.18	
					0.955	Total

Table 13 Master Fusion Table with all 5 Sensors

6. Contact TMA

TMA is handled in the model by reading the status of each contact after it has been processed and by utilizing the confidence values in Table 14. Each contact is sequentially assigned target range and bearing confidence values, which vary from 0 to 1 depending on how well the targets range and bearing are known. The target range confidence is calculated by finding the maximum confidence value from each sensor for a given contact.

Sensor	Possible Outcomes	Target Range Confidence	Target Bearing Confidence
BBG	Non-Detectable	0	0
	Detectable	0	0.8
	Trackable	0.5	0.9
NBG	Non-Detectable	0	0
	Detectable	0	0.8
	Trackable	0.5	0.9
	Classifiable	0.5	1
ES	Non-Detectable	0	0
	Detectable	0	0.2
	Classifiable	0.6	0.8
Imagery	Non-Detectable	0	0
	Trackable	0.6	0.9
	Classifiable	0.9	1
	Identifiable	0.9	1
AIS	Non-Detectable	0	0
	Identifiable	1	1

Table 14 TMA Confidence Values

The target bearing confidence is calculated by taking an average of the confidence values from each of the 5 sensors.

7. Man/Machine Tradespace

Every contact is initially processed by a machine and then there are three possible follow on actions. The first action is that low priority contacts are simply passed on and not looked at by a person. The second action is for some portion of the higher priority contacts to be reviewed by a person in a supervisory role where he has the option to agree with the machines assessment of that contact. The final action is that the man reviews the other two choices are to be reviewed by a person in a supervisory role or to completely reprocess the contact manually.

8. Triggers

Triggers in the model kick off certain processing based on Figure 15. Since this model is probabilistic, these triggers act like thresholds and once exceeded the processing of the contact is initialized. Once the contact arrival trigger was reached the contact was moved to the contact detection function. Once the contact detection trigger threshold was exceeded the contact was moved forward to the identify function. If at any point the contact was not generating a threshold level it would reach an end of life trigger and be considered a stale contact.

9. Simulation Weaknesses

There are two weaknesses in the simulation with respect to those scenarios in which the submarine is not always at PD. The first is that the priority of contacts is not adjusted once the submarine submerges, which may not be a reasonable assumption. While surfaced, all contacts are a concern and become a high priority at close range. Once submerged the model handles non-military contacts as low priority.

The second weakness in the model is how the master fusion table is calculated. As described above, the contact fusion score is adjusted by dividing the fusion score by the maximum value achievable, the sum of all five sensors. When at-depth, there are only two sensors available. When not at PD, this was accounted for in post-processing of the output data, by dividing the fusion score output value by the adjusted maximum contribution of the BBG and NBG sensors and the percent time of the submarine at-depth. The maximum sensor fusion values for each sensor are added together and divided by the max possible fusion score (0.56) to arrive at the fusion score for each contact. Table 15 summarizes the calculations for two sensors.

		Capability Contribution				
		T	C			
	% Sensor Contribution	0.9	1			
NBG	0.4	0.36	0.38		0.38	Max. Score
BBG	0.2	0.18			0.18	
					0.56	Total

Table 15 Master Fusion Table with 2 Sensors

E. DETERMINING SYSTEM PARAMETER VALUES

Using DOE methods, as implemented in the JMP9® software package, and as described in Appendix C, the number of runs and the output values were determined. For this project, the DOE was set up for nine input factors, with both second order and two-way interaction effects. This resulted in 64 runs, as shown in Appendix C.

The following are the operational parameters that represent the tradespace discussed above: percent man for BBG, NBG, Visual Process, ES, Update Tracker, and TMA processes. Other operational parameters are the number of men available to conduct TMA and run the sensor pool. Machine effectiveness versus human effectiveness also contributes to the tradespace parameters. One method to determine the optimum values is to run a series of experiments, with the input values determined by the DOE methods [Yang, 2009]. The JMP9® software analysis package provides a custom DOE module that allows a fractional factorial DOE screening that identifies those input factors to which the system is either sensitive or insensitive. In addition, the software was used to determine sensitivities to interactions between input factors and powers of the input factors. For this project, two way interactions and second order powers were utilized. In order to perform a DOE, the range over which each parameter had to be evaluated was specified. Table 16 below shows the range for each, with rationale for range selection.

<table>
<tr><th>Input Parameter</th><th>Low value</th><th>High Value</th><th>Range Rationale</th></tr>
<tr><td>% Man BBG Process</td><td>25</td><td>75</td><td rowspan="6">High value: The current implementation for each is already somewhat automated, with an estimate of 25% machine contribution (75% man).
Low Value: The basic assumptions on the machine effectiveness and speed of machine based decisions, vice man, would typically drive these parameters to the low end; however, this is limited to 25% as it was felt that full automation of a submarine would be too risky.</td></tr>
<tr><td>% Man NBG Process</td><td>25</td><td>75</td></tr>
<tr><td>% Man Visual Process</td><td>25</td><td>75</td></tr>
<tr><td>% Man ES Process</td><td>25</td><td>75</td></tr>
<tr><td>% Man Update Tracker Process</td><td>25</td><td>75</td></tr>
<tr><td>% Man TMA Process</td><td>25</td><td>75</td></tr>
<tr><td>Number of Men TMA Process</td><td>1</td><td>4</td><td rowspan="2">High Value: The number of operators per shift currently assigned to the task
Low Value: The minimum based on 1 operator per sonar sensor, plus sharing EW, one for TMA, and one for TMA</td></tr>
<tr><td>Number of Men Sensor Pool</td><td>3</td><td>6</td></tr>
<tr><td>Machine Effectiveness relative to man</td><td>0.345</td><td>2</td><td>High value: Based on twice the maximum man effectiveness used in the model.
Low Value: Based on 1/2 of the minimum man effectiveness used in the model.</td></tr>
</table>

Table 16 Combinational DOE inputs

VIII MODELING RESULTS

A. OPERATIONAL PARAMETERS

Table 17 shows the optimal values for the CCS operational parameters resulting from JMP9®'s Optimization analysis of the 64 runs defined by JMP9®'s DOE module, as described above.

% Machine						Number of Operators		Machine Effectiveness
BBG Process	NBG Process	Visual Process	ES Process	Update Tracker Process	TMA Process	TMA	Sensor Pool	
75	75	75	25	75	75	1	3	2

Table 17 CCS Optimized Operational Parameters

B. KEY PERFORMANCE PARAMETERS

The KPPs and their weights for the architectural construct are listed in Table 18. The operational values from Table 17 and Table 18 were then used in the ExtendSim® model and a simulation was run to determine the resulting KPP average values.

Table 18 shows the resulting KPP values and scores with the corresponding CCS score. Also shown are the results for the same operational parameters, with the machine effectiveness set to 0.5 and 1, relative to man effectiveness.

		Simulated CCS KPPs				
		Percent Maintained Contacts	Fusion Score of Contributin g Sensors	Accuracy Measure	Average number of men used	
KPP Bounds / Scoring Run	Scoring weight	0.3191	0.0383	0.0960	0.5470	Score
	Threshold	0.8	0.7	0.5	8	
	Goal	0.999	0.95	0.9	3	
Optimized	Values	1.000	3.480	0.839	3.193	0.965
	Resultant Scores	1.000	1.000	0.848	0.961	
Min Machine	Average Values	0.9974	0.8496	0.7419	3.1888	0.924
	Resultant Scores	0.992	0.598	0.605	0.962	
Mid Machine	Average Values	0.9996	1.3030	0.7997	3.1164	0.964
	Resultant Scores	1.000	1.000	0.749	0.977	

Table 18: CCS KPP Values and Scores

C. ARCHITECTURE

It was demonstrated that the architecture constructs shown in Figure 23 and Figure 24, when implemented with high levels of automation and the KPPs shown in Table 18, would provide a robust CCS.

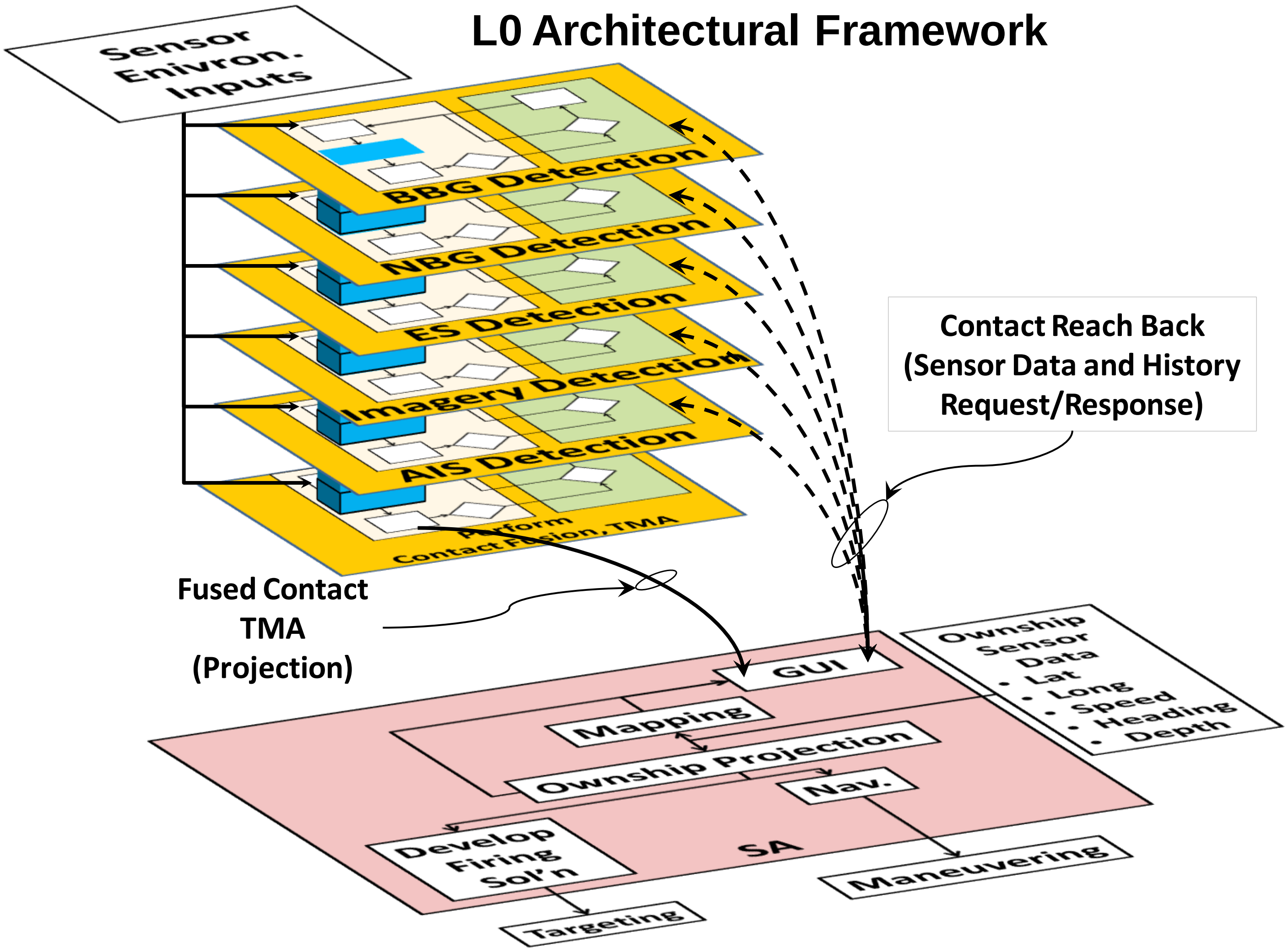


Figure 23: High Level CCS Architectural Framework

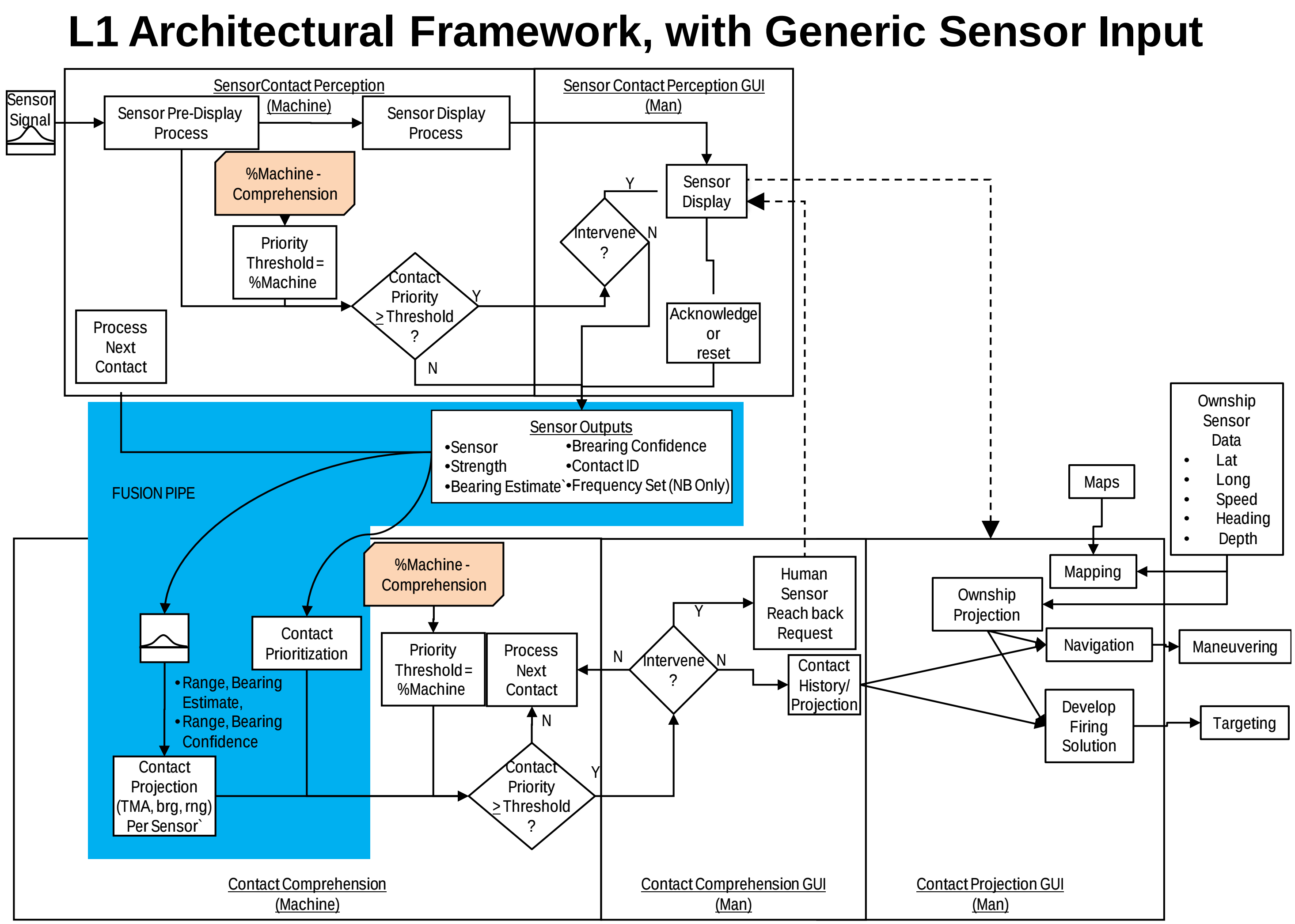


Figure 24: Detailed CCS Architectural Construct

D. COST MODEL

The results of the system modeling and simulation allow a reduction in manpower from between six to ten operators per shift in the current VA operational base-line to four operators per shift, with an average utilization of 34.1%. This 52% reduction in manpower utilization will potentially save the Navy $41.7 million per year.

From the results of the modeling with a high level of automation, the entire combat system personnel per platform decreased from 48 sailors to 23. The four shifts, at four people per shift amounts to 16 CCS personnel. Since the TM rate of seven is assumed to remain constant across current and future systems, this brings the total combat system billet count to 23 as shown in Figure 25. This RTOC amounts to a total CCS personnel savings of 25 per platform and over the course of ten years amounts to a projected yearly savings of nearly $42 Million dollars as shown in Figure 26. The total projected savings over the course of ten years amounts to $465.9 million as shown in Table 19.

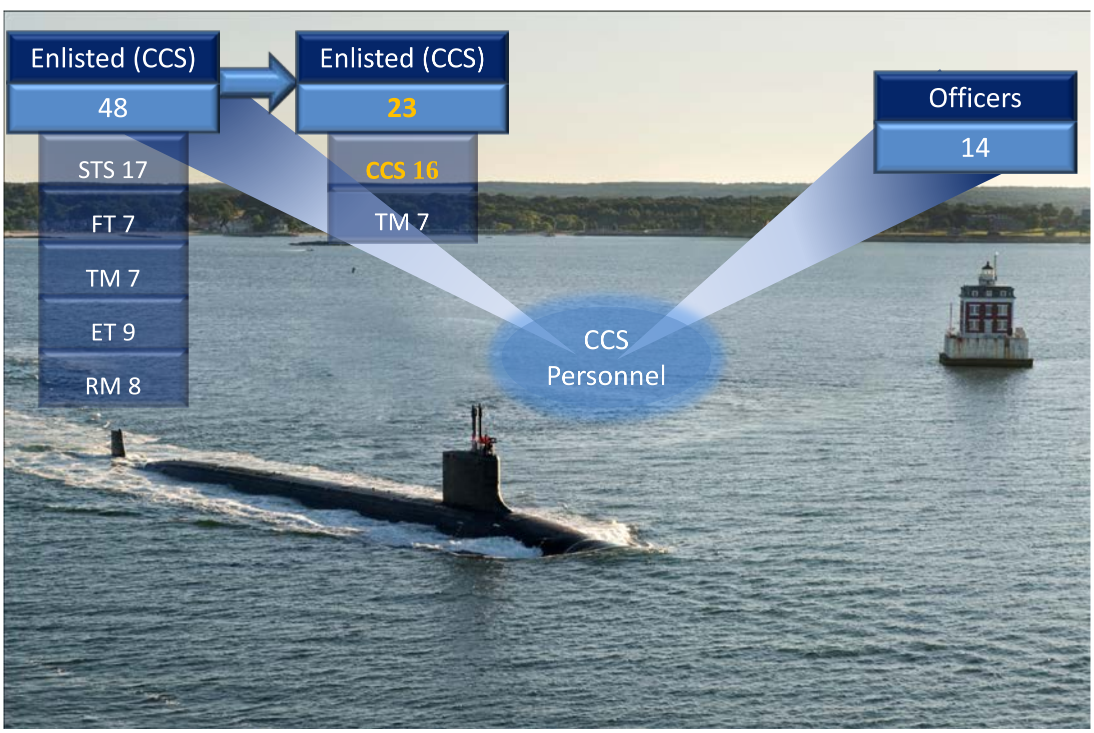


Figure 25: Level of Automation Personnel Reduction.

		VA Fleet Cost Savings Per Enlisted Sailor Reduction							
FY	Index	1	2	3	4	5	6	7	25
2011	1.0000	$1,669,626	$3,339,264	$5,008,896	$6,678,527	$8,348,159	$10,017,791	$11,687,423	$41,740,650
2012	1.0155	$1,695,514	$3,391,028	$5,086,542	$6,782,056	$8,477,569	$10,173,083	$11,868,597	$42,387,847
2013	1.0371	$1,731,579	$3,463,157	$5,194,736	$6,926,315	$8,657,894	$10,389,472	$12,121,051	$43,289,468
2014	1.0649	$1,777,935	$3,555,870	$5,333,805	$7,111,741	$8,889,676	$10,667,611	$12,445,546	$44,448,379
2015	1.0947	$1,827,717	$3,655,435	$5,483,152	$7,310,869	$9,138,587	$10,966,304	$12,794,021	$45,692,934
2016	1.1253	$1,878,893	$3,757,787	$5,636,680	$7,515,574	$9,394,467	$11,273,361	$13,152,254	$46,972,336
2017	1.1568	$1,931,502	$3,863,005	$5,794,507	$7,726,010	$9,657,512	$11,589,015	$13,520,517	$48,287,561
2018	1.1892	$1,985,585	$3,971,169	$5,956,754	$7,942,338	$9,927,923	$11,913,507	$13,899,092	$49,639,613
2019	1.2225	$2,041,181	$4,082,362	$6,123,543	$8,164,724	$10,205,904	$12,247,085	$14,288,266	$51,029,522
2020	1.2568	$2,098,334	$4,196,668	$6,295,002	$8,393,336	$10,491,670	$12,590,004	$14,688,338	$52,458,349
	Totals	$18,637,866	$37,275,745	$55,913,617	$74,551,489	$93,189,361	$111,827,234	$130,465,106	$465,946,659

Table 19 VA Fleet Cost Savings Per Enlisted Sailor Reduction

E. SUMMARY OF RESULTS

Figure 26 depicts the graphical summary from the previous cost analysis. The derived savings above were based on a simple average DUC (salary and other compensation) across all of the enlisted billets in Table 7. An average of DUC was selected to simplify the analysis.

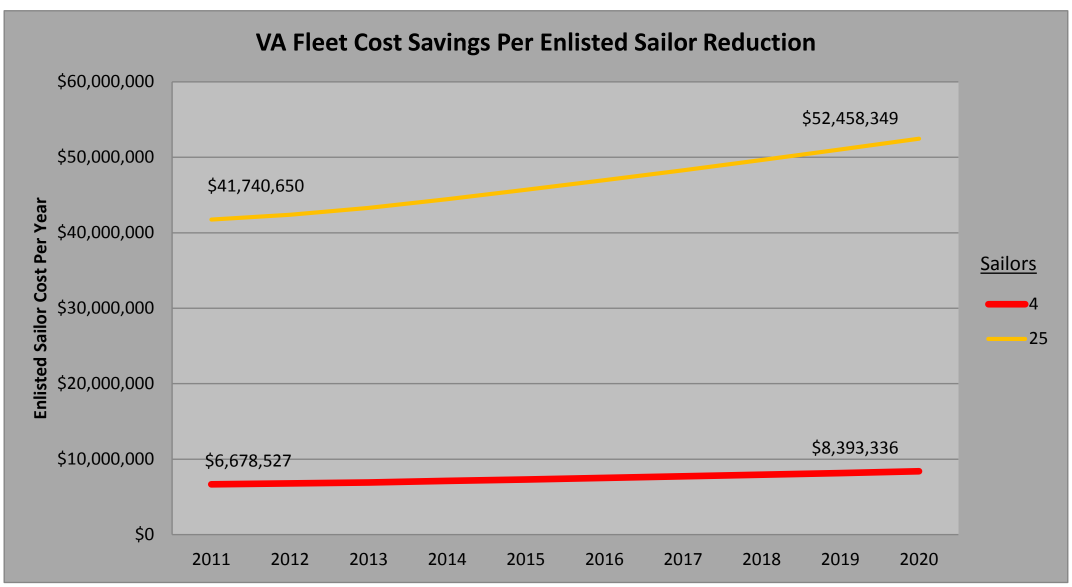


Figure 26 VA Fleet Cost Savings 25 Sailor Reduction

It can be seen from Figure 26 that by reducing the VA submarine force between 4 to 25 sailors between $6.7M and $41.7M. Extending this savings over a ten year period can result in a potential savings between $8.4M to $52.5M.

IX CONCLUSIONS

The intent of this project was to develop a construct to demonstrate that a new approach to the CCS in an end-to-end engagement chain context and high level automation can reduce the CCS TOC to the Submarine Force. It was shown that effective SA with reduced manpower is feasible by adopting a new CONEMPS that achieves the following: (a) allocating the various engagement chain functions to a combination of people and machine, (b) changing from man-as-operator to machine-as-operator, (c) cross training the CC crew to enable the use of personnel pools at the sensors and trackers.

A modified SIMILAR systems engineering model was used to create the construct and define the system functions to construct an ExtendSim® model to evaluate the system under stress case conditions. Based on the DOE, the ExtendSim® model settings were adjusted to measure the KPPs and prove that the CCS can be operated with a crew of four persons per shift. To achieve this level of personnel in the future system development, a new approach to the fundamental operator KSAs, HSI and training systems will need to be implemented by the Submarine Force.

By adopting this change in the system development the reduction in personnel from (48) to (23) can save the Submarine Force on the order of a $42 Million dollars in DUC annually. This reduction amounts to a 52% reduction in manpower utilization which is a projected savings over the course of ten years amounts to $465.9 million dollars. These results are summarized in Table 20. This savings does not account for any of the other annual unit cost savings such as the indirect costs (IC) and maintenance costs (DIC and DDC). The operations and maintenance requirement assessment of the system will be necessary to ensure that the maintenance of the equipment does not burden the personnel based on the overall reduction and collateral duties such as damage control.

Personnel Per Platform			DUC	VA Fleet Ten Year Savings
VA Combat System	CCS	Reduction	$M	
48	23	52%	42	465.9

Table 20 Summary of Reduction Results

The results of the ExtendSim® modeling upheld the reduction in personnel in the CCS based on the proposed CONEMP. The modeling showed that accounting for automation and human effectiveness levels would produce an effective CCS. The model settings validated that the engagement chain functions can be accomplished with high level automation and a minimum of four persons per shift.

The human CCS operator has to act in a more supervisory role, taking a higher level viewpoint of the situational picture. This allows him to not only understand a small niche of data, but also a higher level of information. This required level of information certainty demands a greater level of trust in the system, which has yet to be proven. It is imperative that the human not be removed from the processing loop for a few reasons including:

1. The socio-political risk is too great for a fully automated armed system.

2. Without enough interaction, the human may become complacent, relying on automated outputs and lowering his overall situational mental model correctness.

Increasing automation, yet keeping the man in the processing loop with sufficient workload to maintain vigilance, will effectively elevate him to a supervisory role. This allows the machines to act in an advisory role to the human, affording trust in the data. To support that supervisory role, the human needs to work across multiple sensors. The best way to realize these conflicting requirements is to re-align the human from being an expert in a particular job to becoming a more highly trained “super” operator across several tasks. He also needs to work in a “pool” of human resources that can be applied as required by the situation.

Based on the modeling and analysis completed during this project, it is feasible to implement a CCS that reduces operational cost by a total of $465.9 million dollars over ten years. These results were achieved using the operational values listed Table 21.

% Machine						Number of Operators		Machine Effectiveness
BBG Process	NBG Process	Visual Process	ES Process	Update Tracker Process	TMA Process	TMA	Sensor Pool	
75	75	75	25	75	75	1	3	2

Table 21 Operational Results

It is noted that the machine effectiveness listed in Table 21 may be difficult to achieve due to the investment needed to develop intelligent systems capable of expert operator performance. Thus, further analysis was performed to estimate the system performance with a machine effectiveness assumed to be one-half and equal to man effectiveness. In both cases it was shown that although there is a decrease in system performance, the change is small. Therefore, it is concluded that it is unnecessary to wait for the machine effectiveness to achieve 200 percent of man effectiveness to implement the construct presented.

X RECOMMENDATIONS

A. ROADMAP TO IMPLEMENTATION

In order to implement the derived construct, there are required refinements to the model, as well as certain enabling technologies needed to implement a truly integrated combat system that supports the balance of man to machine demonstrated by this project. It is also anticipated that significant changes in acquisition and employment of the submarine systems will be required in order realize this construct. These changes can be categorized as enabling technologies, follow-on development work, and organizational changes. Changes in the approach to acquisition are anticipated but are beyond the scope of this technical project.

B. ENABLING TECHNOLOGIES

The detailed hardware design, algorithm development and system architecture are beyond the scope of this project. However, factors that must be considered in the design and implementation of a construct that would support the future SCSEP construct are addressed in the following sections.

1. Architectural Elements

The inclusion of modern components and forms of implementation, such as massively parallel processing, self-learning, fuzzy logic, genetic and heuristic software elements should be investigated to increase system effectiveness. These can be introduced as adjunct elements that override the current approach of pre-programmed algorithms that exist in a fixed stove-piped procedural architecture.

2. Hardware

Key factors in the selection of hardware are the efficient sharing of resources, commonality and redundancy. Servers that can be utilized for diverse processing functions will enable efficient use of the hardware. For example, processing power allocated to imaging and ES during PD operations will be reallocated to sonar processing while submerged. Similarly, while preparing for and at PD, these same processors will reallocate near real time to support the varying sensor loads.

Commonality in the hardware will be crucial both to support the allocation of varying sensor loads and to enable the concept of pooled maintenance divisions. By utilizing common hardware across the platform, the need for specialized technicians will be reduced.

Redundancy in the hardware and the failure modes of the architecture must be fully considered and addressed in the design of the future SCSEP. Due to the severe consequences involved, all hardware must be fail safe and critical hardware must be designed to allow for manual operations in the event of failure. The failure modes must be such that failures allow the operator to maintain SA by a gradual transition from higher to lower level of automation.

3. Algorithm Development

The algorithms developed to support the SCSEP construct must be functionally verified and reliable. As previously discussed, the crew must trust the automation. Since the undersea acoustic performance is environment dependent, both in-lab and at sea testing would be required to certify the algorithms. Similar to the hardware, the algorithm development must produce software with high reliability and graceful failures.

Redundancy in the functions will provide reliability both in the execution of the functions and in the error checking of the functions. Multiple independent algorithms error checking each other will provide a more robust design that will serve to reduce single points of failure and will better account for the extremes of the operating environments.

Limitations of the algorithms must be accounted for in the failure modes. The algorithms must account for their inherent limitations and provide a graceful transition to lower levels of automation as system limitations are approached and exceeded. Fail safe and operational requirements must be considered and appropriate requirements allocated to the algorithms during the design stage.

4. Machine Effectiveness

Machine effectiveness is a combination of algorithm and machine efficiency, and algorithm accuracy. Table 16 shows that there are small changes in system performance relative to machine effectiveness when the machine is set to a range of 0.5 to 2 times human effectiveness. Therefore, this construct can be introduced once the lower level of machine effectiveness is achieved.

The perception engine must be better able to perform computations and output advisory contact information. While automation is partially implemented now in the form of trackers and bell ringers, the scope of automation needs to be greatly expanded in order to enable the suggested architecture. This research is ongoing at a sub-system and stove-piped level, but advances in this area, across sensors will be required.

In order to allow the human to trust the machine, algorithms must be advanced to lower the number of both type I (false alarms) and type II errors (missing a real contact). As suggested in the Model Design section, "the expectation of detecting a genuine target must be at least ten times the expectation of encountering a false alarm" [Chapel, 2010]. Without this low false alarm technology, the automation will not be trusted, resulting in the human trying to do too much of the work himself. In this case, the operators will either:

- Shed tasks, thus becoming less effective, or
- Miss needed contacts, or
- Contacts will be prosecuted cursorily.

This could result prioritizing a contact incorrectly.

5. Human System Integration

HSI is a critical component of any design. However, in a highly automated design such as the SCSEP, the effective integration of the human operators and the automation is particularly essential. The data processed by the automation must be displayed as actionable information to the operators. In addition to the data processing algorithms, automation to prevent and detect human error will be a key factor in a successful design to support reduced manning. With low levels of automation, the increased manning levels provide multiple eyes checking the information processed by the operators and the decisions made by the supervisors. With reduced manning, the automation must account for this element of human error checking. Trip wires should be determined and bell ringers implemented to alert the supervisor when potential human error is detected.

C. OTHER FOLLOW-ON WORK

1. More Detailed Functional Decomposition

For the model, only the Level 1 functions, as described in the functional decomposition shown in Table 3and Figure 7 were considered. This work could be extended to a more detailed look at the tasks and thus perhaps improved effectiveness requirements for implementation of automation.

Figure 15 shows the distributions used for TMA and Data Fusion. While it was outside the scope of this report to actually implement these algorithms, the distributions used were derived from interviews and personal experience. Further research could be performed to confirm or update these numbers, including research that would investigate new techniques and algorithms that might improve these values. This would involve looking at newer techniques for tracking contacts, or fusing data across sensors.

2. Expand the "Projection" Portion of SA into the Effectiveness Equation

In the decomposition of SA "projection", it was determined that to actually simulate the "act" portion of the engagement chain would be very complicated. This is due to the fact that models of people would be required to simulate performing actions and interpret mission requirements. For example, when the platform comes across a contact, it could shoot or maneuver. Whether to shoot or not requires understanding of the mission: Is the object of the mission to actually eliminate the contact? If not, there are ramifications to doing so. Indeed, it is an assumption that the submarine command will make the correct decision given good information. A method of advancing the mission requirements into the model, or even a better value for how well command responds to a situation, could be investigated.

3. Additional Sensors

Only certain sensors were considered, partially to keep this report unclassified. Additional sensors could be considered such as active sonar. As another example, reliable ship-to-ship communications might be considered to share sensor and contact data across platforms. Once these are considered, the results from the sensors could be improved by allowing directed searches, or being cued to specific contacts. This is an extension of the "fusion pipeline" discussed above, and the net effect would be a consolidated federation of networked sensors.

4. More detailed Understanding of the Cost of Manning

Consider all the costs involved in manning, not just the direct costs. There are many costs to manpower: training, room, board, equipment, salary, support (secretaries, human resources offices), overhead (heat, light and paper), etc. As a result of the reduced personnel, overall reductions in cost can be realized in terms of onboard support equipment such as computer infrastructure and tooling; as well as a reduction in land based administrative support requirements.

5. Other Possible Related RTOC Sources

In addition to the manpower cost savings, there are other areas where cost savings can be gained as part of technology upgrades to the CCS. As the manpower reduction is realized, there could be a corresponding decrease in the needed foot print:

- Reduced habitability; rack, oxygen generation, personal safety equipment, provision storage and galley space, or
- Reduced number of operator workstations.

This reduction in habitability and equipment footprint would provide much needed areas for additional hardware, cabling and systems needed to provide a reliable automated CCS.

D. IMPLEMENT FINAL FUNCTIONAL ALLOCATION, ACCORDING TO ORGANIZATIONAL CHANGES

It is anticipated that the reduced manning and changes in employment will require changes in the crew organization. Currently the crew is organized by departments, which are further organized into divisions. Departments are led by officers who serve as department heads. The department heads are responsible for the divisions that make up their department. The divisions are managed by junior officers who serve as division heads. A senior enlisted crew member or lead petty officer (LPO) coordinates with the division head to manage the enlisted crew that comprise the division. The division heads manage both the operational and maintenance duties of the crew. The current organization is based partly on the stove piped employment of the sensors. The left of Figure 27 shows the current divisions on the VA class submarine [USS New Mexico, 2011]. It is anticipated that the organization of the divisions will be modified resulting in fewer divisions. Additionally, it is anticipated that the division organization will be further subdivided into operational divisions and maintenance divisions as shown on the right of Figure 27.

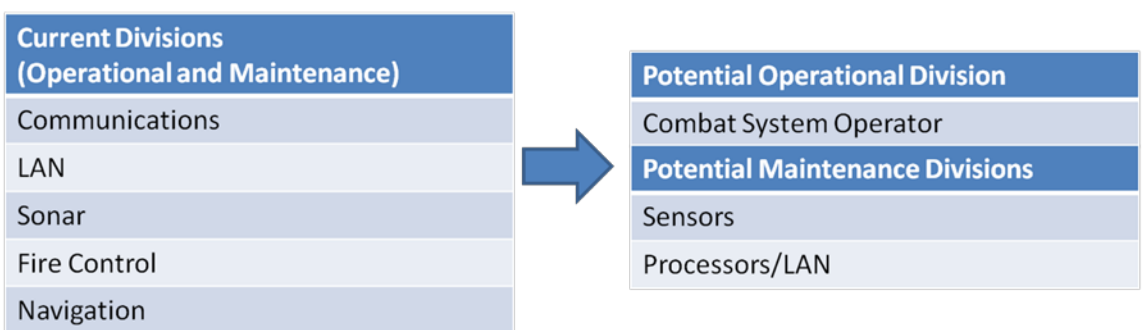


Figure 27 Personnel Breakdown

1. Operational Divisions and Maintenance Divisions

The enlisted crew members responsible for the combat systems have two primary functions, which are to serve as operators and maintainers. Currently the enlisted fleet that comprises the Submarine Electronics / Computer Field (SECF) is organized by specialty ratings identified as Sonar Technician Submarine (STS), Fire Control

Technician (FT), and Electronics Technician (ET). The ET rate is further divided into Navigation (ET-Nav) and communication (ET-Comms). [Powers, 2011] The crew that fill these ratings have specialized training based on the unique sensors they maintain and operate. Just as the combat system will be re-architected to eliminate the stove piped sensors employment, the divisions will need to be organized to eliminate the stove piped operator concept. A pool of independent sensor operators must be available. These operators will adjust their focus as the operational environment dictates. For example, while submerged deep in an environment saturated by acoustic contacts, operators will process the automation representation of the sonar sensor information. As the submarine arrives at PD, and visual and ES contacts increase, more operator focus could potentially utilize the automation output of the fused sensor data from all available sensors. The old CONEMP dependent on Sonar operators and ES operators and Imaging operators will be replaced by a revised CONEMP, which involves versatile combat system operators.

Similarly, the officers and supervisors will need to adapt to supervise the combat system as opposed to supervising sensor specific data. The legacy Fire Control Technician of the Watch (FTOW) and Sonar Supervisor roles would be replaced by a single combat system supervisor in low contact density environments. As the contacts in the environment increase, an additional combat system supervisor could be called upon from the supervisor pool.

The focus of this report is on the operational aspects of the combat system but the required maintenance cannot be totally ignored. Therefore, it is anticipated that the maintenance divisions will be reorganized into specialized sensor specific maintainers and sensor diagnostic computer system and LAN maintainers. This organization allows the reduction in manning realized by replacing the stove piped specialized operators not to impact the maintainability of the equipment. The same pooled operators will support maintenance of the common hardware utilized for backend sensor processing. Due to the uniqueness of the sensors, it is anticipated that a small specialized sensor maintenance division will still be required but reduction in the overall maintenance force will still be realized.

2. Changes in Training

As discussed, the roadmap must include migration from stove-piped division of operators within the SECF to a pooled SECF division of operators. The enlisted technicians would need to be cross-trained as operators. This pool of operators must also be trained to function as a pool of maintainers for the common equipment. While the need for specialists to support unique sensor maintenance cannot be eliminated, the roadmap must reduce the number of specialized roles.

3. Changes in Culture

Automation is implemented for two primary reasons: to reduce operator workload and to increase vessel safety and effectiveness. To be successful, the end user must effectively work with the automation, using and trusting the tools, but also understanding what automation is doing. If the user does not trust the automation then it will not be accepted and will not be used. Conversely if the user places too much trust in the automation then catastrophe can result if the automation fails or when the limits of the automation are exceeded and manual control must be regained instantly.

"The Navy is a service of custom and tradition" [Bundy, 2010]. The roadmap to implementation must address the changes in custom and tradition, which will be represented by the elimination of stove-piped sensor based operators and the introduction of pooled combat system operators. It is anticipated that time will be required for the crews to become accustomed to the changes represented by this new CONEMP. This is similar to the time that was required for the crews to become familiar with and accepting of visual sonar waterfalls as opposed to aural sonar and the transition from optical based imaging to sensor based imaging. The critical factor required for acceptance of the change will be trust in the new CONEMP and trust in the algorithms that make the new CONEMP realizable.

Paramount to building trust in the automation CONEMP is data confidence. For man to trust the automation he needs to understand why the algorithm is making any given recommendations. Man usually trusts the algorithm if it is recommending low risk maneuvers. It is when the algorithm recommends something that is risky that man questions it. Man then spends time questioning the algorithm instead of reacting. The man needs to be able to sense when to question what the automation is reporting. Otherwise, if it breaks he will not know how to react and he will not know when it has failed. An example is autopilot on airplanes – the pilots trust the automation but they also are trained to know when they need to take over.

In order to support a gradual shift in culture, a phased approach could be implemented where the levels of automation increase as the data confidence and the Fleet's trust of automation increases. The more the automation increases, the more critical it will become for fail safe implementations, which provide redundancy not just in the hardware but also in the software to eliminate single point failures. Studies have shown that when automation failures occur that require the user to return to full manual control, the higher the Level of Automation (LOA) at the time of the failure, the more difficult it is for the operator to return to manual control [Di Nocera, 2005]. With a highly automated CCS, it could be catastrophic if the automation failed and the crew had limited time to regain control and regain SA at the level required for full manual control. Therefore, the automation that will allow the reduction in personnel must be implemented to allow graceful degradation and must be fail-safe.

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XIII APPENDIX A: ACRONYMS

AIS	Automatic Identification System
AoA	Analysis of Alternatives
ARIS	Automated Readiness Information System
BBG	Broadband Gram
C2	Command and Control
CBO	Congressional Budget Office
CC	Combat Control
CCE	Combat Control Efficiency
CCF	Completeness of Comprehension (fusion)
CCS	Combat Control System
CCT	Correctness of Comprehension (TMA)
CHENG	Chief Engineer
CM	Contacts Maintained
COC	Contact of Concern
COI	Contact of Interest
CONEMP	Concept of Employment
CONOPS	Concept of Operations
CRS	Congressional Research Services
CS	Combat System
DDC	Direct Depot Cost
DEVRON-12	Submarine Development Squadron Twelve
DIC	Direct Intermediate Cost
DoDAF	Department of Defense Architecture Framework
DOE	Design of Experiment
DTIC	Defense Technical Information Center
DUC	Direct Unit Cost
EFFBD	Enhance Functional flow Block Diagram
ES	Electronic Sensor
ESM	Electronic Surveillance Measure
ET	Electronics Technician
ET-Comms	Communications

ET-Nav	Navigation
FBCM	Fused Bearing Confidence Mean
FRCM	Fused Range Confidence Mean
FSM	Fusion Score Mean
FT	Fire Control Technician
FTOW	Fire Control Technician of the Watch
GAO	Government Accountability Office
HSI	Human System Interface
IC	Indirect Cost
IDEF0	Integration Definition for Process Modeling
IFF	Identification Friend or Foe
INCOSE	International Council of Systems Engineers
IPR	In Process Review
ISR	Intelligence, Surveillance, Reconnaissance
KPP	Key Performance Parameter
KSA	Knowledge, Skills and Abilities
LAN	Local Area Network
LOA	Level of Automation
LOS	Line of Sight
LPO	Leading Petty officer
ME	Mission Effectiveness
MLO	Mind-like Objects
MOE	Measures of Effectiveness
MOM	Measures of Merit
MOP	Measures of Performance
NAVSEA	Naval Sea Systems Command
NBG	Narrowband Gram
NPS	Naval Postgraduate School
NSMRL	Naval Submarine Medical Research Laboratory
NSWCCD	Naval Surface Warfare Center Carderock Division
NUWCDIVNPT	Naval Undersea Warfare Center Division Newport
NWC	Naval War College
OOD	Officer of the Deck

OV-1	Operational View 1
PARM	Program Acquisition Resource Manager
PBB	Passive Broadband
PD	Periscope Depth
PEO SUB	Program Executive Office, Submarines
PNB	Passive Narrowband
RCN	Rating Control Number
ROE	Rules of Engagement
RTOC	Reduced Total Ownership Cost
SA	Situational Awareness
SCSEP	Submarine Combat Systems Engineering Project
SEAL	Sea, Air and Land
SECF	Submarine Electronics / Computer Field
SIMILAR	State, Investigate, Model, Integrate, Launch, Assess Re-evaluate
SME	Subject Matter Expert
SNR	Signal to Noise Ratio
SOF	Special Operations Forces
STS	Sonar Technician Submarine
TM	Torpedo Man
TMA	Target Motion Analysis
TOC	Total Ownership Cost
TPM	Technical Performance Measure
UNTL	Universal Naval Task List
USN	United States Navy
VA	Virginia
VAMOSC	Visibility and Management of Operating and Support Costs
VHF	Very High Frequency

XIV APPENDIX B: ASSUMPTIONS

The following section outlines the various assumptions that were made throughout the engineering effort.

A. SCSEP PARADIGM SHIFT

An assumption of this SCSEP project is that a paradigm shift will be required in the way the systems are developed, utilized and organized, resulting in higher "people-ware" efficiencies. The current stovepiped programs of record independently create acquisition systems as part of new construction and modernization programs with differing development schedules. In addition to the systems being developed independently, the operator training products are developed independent of other systems.

To achieve the goal of a single end-to-end system, the consolidation of the system development would need to occur to focus specifically on creating a single CCS system. Interfaces for a consolidated CCS would focus on the data flow to ensure that the correct information is exchanged between system functions. The sensor operator interface would need to be created to present situational knowledge instead of low level scientific data.

To operate the system, CCS sensor operators will need to be trained in technical areas that are currently billeted across several current shipboard systems. The operator pool concept that is introduced in this project leverages the cross trained operator KSAs to achieve a better utilization of the sensor operator's time "people-ware" efficiencies.

B. HUMAN VERSUS MACHINE TRADESPACE

The intent of this project is to assess the feasibility of replacing the functionality of the CCS with machine based processing by varying the functional human versus machine ratio in the detection, identification, tracking, decision, engagement and assessment of the submarine engagement chain. This effort results in an overall analysis into the staffing levels for the Combat System including STS, FT, TM, ET and

Radioman. With a shipboard compliment of (48) CS persons, a reduction in personnel could achieve a significant cost savings.

C. FOCUS ON COMBAT CONTROL ONLY

To quantify the RTOC the analyses that are contained within this report are focused on the level of manning specific to the combat system. The team realizes that there are other responsibilities associated with non-combat system related functions such as damage control, equipment maintenance, messing, berthing and general housekeeping. The impacts to the overall reduction outside the combat system are not considered. In addition, the team assumes that there will be no negative consequences incurred as a result of reducing personnel.

The TM rate was not included as part of the overall reduction in the CCS operator pool calculations. The focus was on the inboard processing of the sensor data up to the point of decisions to act, therefore all components of the weapons programming, placement and launch control were omitted from this project. Also, the operations perspectives of the CCS were identified with respect to personnel only. The maintenance activities and approach will need to be evaluated in a similar method to substantiate the final reduction in Submarine CCS personnel.

D. VIRGINIA CLASS SUBMARINE IS OUR COMPARISON BASELINE

The RTOC analysis recognizes that the physical dimensions of the submarine platform are centered on the shipboard complement of crewmembers. The assumption for sake of simplicity is that the current Virginia Class submarine is the baseline hull design and that any reduction of hull size as a result of manning reduction is left for future analysis and is beyond the scope of this project.

E. CURRENT SENSOR SUITE PERFORMANCE NOT CONSIDERED

This report assumes that the outboard sensor suite provides the necessary signal to noise ratio visual and frequency cues needed to exceed the detection thresholds of the receiving systems. The variability in the contact detections are representative of gaining and losing contacts and are indicative of environmental or kinematic effects of the target.

Improvements to detection algorithms and sensor display of sensor data are not within scope of this project.

F. CURRENT SENSOR SUITE PERFORMANCE IS ADEQUATE

The overall system development and implementation of the sensors will provide the necessary performance capacity to successfully execute the combat system requirements. The system must demonstrate high reliability in order for the operators to have trust in the system output. The system reliability is assumed to be accounted for by expert hardware and software developers with sufficient experience levels, data processing, memory capacity and algorithm confidence. These attributes are necessary for a reliable and trustworthy system.

G. PASSIVE SONAR ONLY

This project team considers the passive sonar system and omits the active system to simplify the overall system requirements and modeling effort. This active sonar aspect of the combat system is left for future students to evaluate and assess for Fleet based implementation.

H. WORST CASE CONTACT DENSITY IS IN THE MEDITERRANEAN

The contact arrival rate for the transit from the homeport to the combat operating area will generate the highest contact loading for the engagement chain. The worst-case transit point identified via AIS analysis is the Straits of Gibraltar where the shipping density was on the order of 130 non-warship contacts per hour. Based on the AIS contacts shown in the VT Explorer® software, the greatest contact density appeared to be in the Mediterranean Sea. The VT Explorer® software was used to determine the contact density of a given timeframe, over the course of a two to four hour period in the Gibraltar area. The identified vessels were binned into the categories of pleasure, merchant and warship. The resultant data was used as an input into the SCSEP model as a stress case for the contact overload condition.

I. EFFICIENCY IS A BETTER METRIC THAN SIMPLE MANNING REQUIREMENTS

Efficiency is the overarching metric for this project. It is a function of contact processing effectiveness and cost. The effectiveness is defined as the ability of the combat system to process and assess the threat versus non-threat contacts vice the specifics of the platform performance in a given environment. With the goal of RTOC, the project team members agreed that a meaningful metric of CC efficiency would be defined as the effectiveness of the SCSEP compared to the number of people operating the equipment.

J. ONLY DIRECT COST IN MANNING IS CONSIDERED

The cost model accounts for the direct unit cost elements that are related to each platform and does not account for the potential savings in terms of housing, medical, sustainment and specialized training that are necessary to support individuals throughout their careers. The approach to RTOC estimation for cost savings was to address reduction of tangible personnel specific costs and relate that cost to a manning reduction in CCS operations. The cost savings from a submarine platform Life Cycle and Submarine Force personnel indirect cost perspective was considered a separate topic outside the scope of this systems engineering project. The indirect cost could be a makeup of food, clothing, health care, entertainment and other necessities. To meet the timeline and to fit within the scope of the project these costs were left to future studies.

K. COMMAND PERSONNEL WILL MAKE THE CORRECT DECISIONS GIVEN THE CORRECT SITUATIONAL PICTURE

Part of the engagement chain is to “engage” or “act”. What constitutes that action depends upon both the current situation and the mission requirements. Since the project team cannot know a priori what the mission requirements are, the assumption was made that the submarine command structure has enough experience to make the right action decision if provided with the best possible current situational picture.

XV APPENDIX C: SIMULATION EXPERIMENTAL DESIGN AND ANALYSIS

The following sections address the experimental analysis that was conducted throughout the project.

A. SCSEP FIRST MODEL RUN OUTPUT DISTRIBUTION ANALYSIS

The input parameter set for the DOE were in accordance with the process in [Yang 2009]. The DOE functional relationship takes the form:

(8)

Converting the input factors for the SCSEP project:

(9)

where x_1 - x_9 are:

- Man BBG Process,
- Man NBG Process,
- Man Visual Process,
- Man ES Process,
- Man Update Tracker Process,
- Man TMA Process,
- Men TMA,
- Men Pool,

- Machine Effectiveness.

The above inputs represent three categories: allocation of the percentage of personnel assigned to a particular process, the number of personnel available and the effectiveness of the machine system when compared to personnel.

To initiate the DOE, the inputs to the Input, Process, Output (IPO) diagram in Figure 28 was created to illustrate the effects in the model and the output. The input ranges for the model are shown in Table 22.

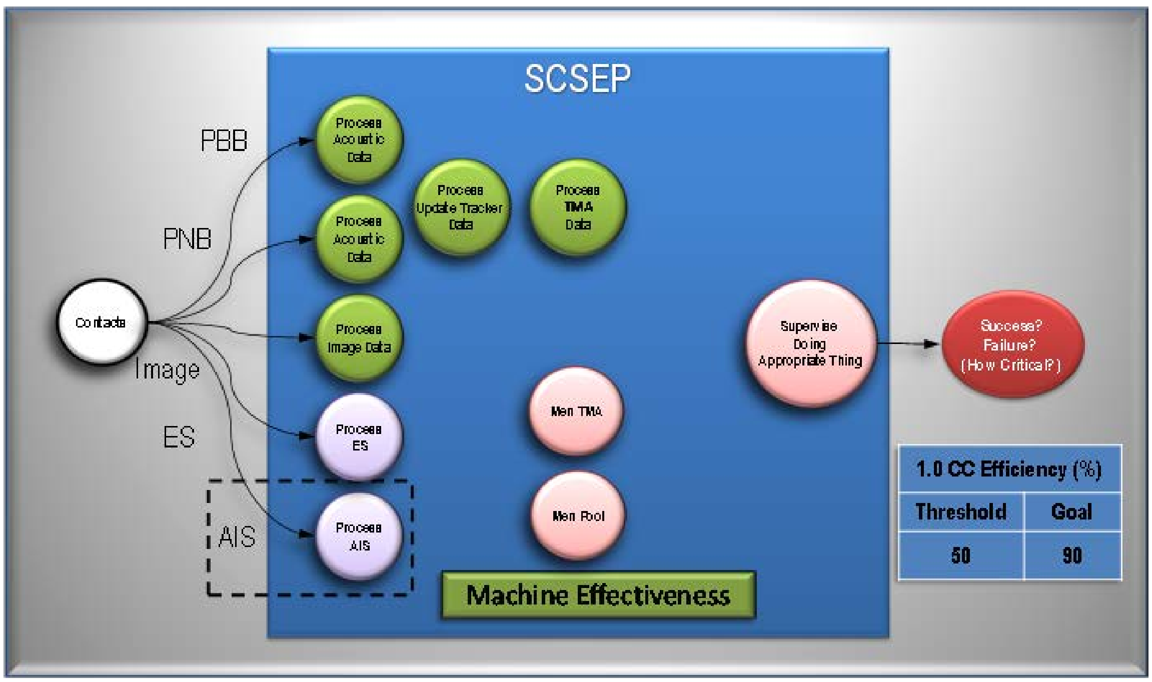

Figure 28 SCSEP IPO Diagram

1. Custom Factorial Design

The two level full factorial designs would require factors on the order of 2^9 combinations, or a total of 512 combinations. Yang has identified that higher order interaction effects can be excluded and reduced to a fractional factorial design [Yang 2009]. The JMP9® software was used to create a custom DOE model representation of the SCSEP project using the Custom DOE worksheet. To create the worksheet the software requires inputs (factors) and outputs (responses) to establish the model. By selecting the two level categorical factors, the interactions between the inputs are calculated as shown in equation (9) above.

Input Factor	*Min*	*Max*	Units
Man BBG Process	25	75	(%)
Man NBG Process	25	75	(%)
Man Visual Process	25	75	(%)
Man ES Process	25	75	(%)
Man Update Tracker Process	25	75	(%)
Man TMA Process	25	75	(%)
Men TMA	1	4	People
Men Pool	3	6	People
Machine Effectiveness	0.345	2	

Table 22 SCSEP DOE Inputs

JMP9® was used to design a custom DOE with two power and two interaction levels. The minimum and maximum input levels are shown in Table 22. The fractional factorial requires the lower order interactions of the inputs defined in Table 22. The JMP9® software develops the model parameters by determining the model terms, resulting in forty-six (46) model combinations as shown in Table 23. Each combination has the minimum and maximum converted into (-1) and (+1) notation to determine the interactivity of the factors.

Combination	Factors/Interactions	
1	Man BBG Process	
2	Man NBG Process	
3	Man Visual Process	
4	Man ES Process	
5	Man Update Tracker Process	
6	Man TMA Process	
7	Men TMA	
8	Men Pool	
9	Machine Effectiveness	
1^2	(Man BBG Process)^2	
2^2	(Man NBG Process)^2	
3^2	(Man Visual Process)^2	
4^2	(Man ES Process)^2	
5^2	(Man Update Tracker Process)^2	

Combination		Factors/Interactions	
6^2		(Man TMA Process)^2	
7^2		(Men TMA)^2	
8^2		(Men Pool)^2	
9^2		(Machine Effectiveness)^2	
1	2	Man BBG Process	Man NBG Process
1	3	Man BBG Process	Man Visual Process
1	4	Man BBG Process	Man ES Process
1	5	Man BBG Process	Man Update Tracker Process
1	6	Man BBG Process	Man TMA Process
1	7	Man BBG Process	Men TMA
1	8	Man BBG Process	Men Pool
1	9	Man BBG Process	Machine Effectiveness
2	3	Man NBG Process	Man Visual Process
2	4	Man NBG Process	Man ES Process
2	5	Man NBG Process	Man Update Tracker Process
2	6	Man NBG Process	Man TMA Process
2	7	Man NBG Process	Men TMA
2	8	Man NBG Process	Men Pool
2	9	Man NBG Process	Machine Effectiveness
3	4	Man Visual Process	Man ES Process
3	5	Man Visual Process	Man Update Tracker Process
3	6	Man Visual Process	Man TMA Process
3	7	Man Visual Process	Men TMA
3	8	Man Visual Process	Men Pool
3	9	Man Visual Process	Machine Effectiveness
4	5	Man ES Process	Man Update Tracker Process
4	6	Man ES Process	Man TMA Process
4	7	Man ES Process	Men TMA
4	8	Man ES Process	Men Pool
4	9	Man ES Process	Machine Effectiveness
5	6	Man Update Tracker Process	Man TMA Process
5	7	Man Update Tracker Process	Men TMA
5	8	Man Update Tracker Process	Men Pool
5	9	Man Update Tracker Process	Machine Effectiveness
6	7	Man TMA Process	Men TMA
6	8	Man TMA Process	Men Pool
6	9	Man TMA Process	Machine Effectiveness
7	8	Men TMA	Men Pool
7	9	Men TMA	Machine Effectiveness
8	9	Men Pool	Machine Effectiveness

Table 23 DOE Interaction Factor List

2. KPPs evaluated

	Percent Maintained Contacts (KPP_1)	Fusion Score of Contributing Sensors (KPP_2)	Accuracy (KPP_3)	#Men used (KPP_4)	
Weight	**0.3191**	**0.0383**	**0.0960**	**0.5470**	
Threshold	0.8	0.8	0.7	8	
Goal	0.999	0.95	0.9	3	Evaluation Score

Table 24 KPP Assessment

3. Output Responses Used To Evaluate the Runs

To calculate the output values, the following four responses were determined by the DOE model:

- Percent maintained contacts (CM)
- Completeness of Comprehension: Fusion (CCF)
- Correctness of Comprehension: TMA (CCT)
- Number of men required per shift (n)

KPP ExtendSim® Output	Percent Maintained Contacts	Fusion Score of Contributing Sensors	Accuracy Measure	# Men used
# Men TMA				X
# Men Pool				X
Fusion Score Mean (CCF)		X		
BBG Status 1	X			
BBG Status 2	X			
NBG Status 1	X			
NBG Status 2	X			
NBG Status 3	X			
Visual Status 2	X			
Visual Status 3	X			
Visual Status 4	X			
Bearing Confidence Mean			X	

KPP ExtendSim® Output	Percent Maintained Contacts	Fusion Score of Contributing Sensors	Accuracy Measure	# Men used
Range Confidence Mean			X	
BBG Excessive Wait (stale target)	X			
NBG Excessive Wait (stale target)	X			
Visual Excessive Wait (stale target)	X			
TMA Utilization mean(%)				X
Pool Utilization mean(%)				X

Table 25 Mapping Model Components to the KPPs Modeled

The DOE resulted in the Table 26.

Run	% Man BBG	% Man NBG	% Man Visual	% Man ES	% Man Update Tracker	% Man TMA	# Men TMA	# Men Pool	Machine Effectiveness	Resulting Score
1	0.25	0.5	0.25	0.25	0.25	0.75	4	6	2	0.68361845
2	0.25	0.75	0.5	0.75	0.25	0.75	4	6	0.345	0.57197517
3	0.75	0.75	0.25	0.25	0.25	0.25	1	3	2	0.90252514
4	0.5	0.5	0.5	0.75	0.75	0.75	3	3	2	0.7422604
5	0.75	0.5	0.75	0.75	0.25	0.75	1	6	0.345	0.61825469
6	0.5	0.75	0.75	0.75	0.25	0.25	3	3	0.345	0.82667932
7	0.75	0.25	0.5	0.25	0.25	0.75	1	6	2	0.69662336
8	0.75	0.75	0.5	0.75	0.25	0.25	1	6	1.1725	0.66736508
9	0.25	0.25	0.75	0.25	0.75	0.25	3	3	2	0.90247607
10	0.75	0.25	0.75	0.75	0.5	0.5	3	5	0.345	0.59064209
11	0.75	0.5	0.75	0.25	0.25	0.25	3	6	2	0.75329901
12	0.25	0.75	0.25	0.75	0.75	0.25	1	3	2	0.84486423
13	0.25	0.25	0.25	0.5	0.25	0.75	1	6	0.345	0.63708733
14	0.75	0.75	0.75	0.25	0.75	0.75	3	6	0.345	0.46236265
15	0.75	0.75	0.75	0.75	0.75	0.75	1	6	2	0.49346882
16	0.25	0.5	0.75	0.75	0.5	0.25	4	3	2	0.85851432
17	0.75	0.75	0.25	0.25	0.75	0.5	4	3	2	0.75819208
18	0.25	0.25	0.75	0.75	0.75	0.75	1	3	1.1725	0.8076227
19	0.25	0.25	0.75	0.75	0.25	0.75	3	6	2	0.7079838
20	0.75	0.25	0.25	0.25	0.25	0.25	1	6	0.345	0.72924527
21	0.75	0.25	0.5	0.5	0.25	0.5	4	3	1.1725	0.84760856
22	0.75	0.25	0.25	0.5	0.75	0.25	1	6	2	0.59785916
23	0.5	0.75	0.25	0.75	0.75	0.75	1	5	0.345	0.5629718
24	0.25	0.75	0.75	0.25	0.25	0.75	1	3	2	0.80890232
25	0.25	0.25	0.25	0.75	0.25	0.5	4	3	0.345	0.80740589

Run	% Man BBG	% Man NBG	% Man Visual	% Man ES	% Man Update Tracker	% Man TMA	# Men TMA	# Men Pool	Machine Effectiveness	Resulting Score
26	0.75	0.75	0.75	0.25	0.75	0.25	1	3	1.1725	0.80907624
27	0.25	0.75	0.75	0.25	0.25	0.5	1	6	0.345	0.64193381
28	0.75	0.25	0.75	0.75	0.25	0.25	1	3	2	0.90310743
29	0.75	0.25	0.75	0.75	0.75	0.25	4	6	2	0.57892349
30	0.25	0.25	0.5	0.75	0.75	0.25	1	6	0.345	0.53386447
31	0.75	0.75	0.25	0.25	0.25	0.75	4	5	0.345	0.63999783
32	0.25	0.75	0.25	0.25	0.75	0.75	1	6	2	0.52355981
33	0.75	0.25	0.25	0.75	0.75	0.75	4	6	0.345	0.44768588
34	0.25	0.75	0.75	0.25	0.75	0.5	4	3	0.345	0.71852303
35	0.25	0.25	0.75	0.25	0.25	0.25	1	3	0.345	0.87152614
36	0.75	0.75	0.75	0.25	0.25	0.25	4	3	0.345	0.84536655
37	0.5	0.75	0.75	0.25	0.5	0.75	4	6	2	0.48522334
38	0.5	0.25	0.25	0.75	0.25	0.25	4	6	2	0.76749173
39	0.75	0.25	0.25	0.75	0.75	0.25	4	3	0.345	0.84023196
40	0.25	0.75	0.75	0.75	0.5	0.75	1	3	0.345	0.70342472
41	0.25	0.25	0.75	0.25	0.25	0.75	4	3	0.345	0.76827823
42	0.75	0.25	0.75	0.25	0.75	0.75	4	3	2	0.81179615
43	0.75	0.75	0.75	0.75	0.75	0.75	4	3	0.345	0.61722312
44	0.25	0.75	0.25	0.25	0.75	0.25	1	3	0.345	0.78397653
45	0.25	0.75	0.25	0.75	0.25	0.75	4	3	2	0.8092077
46	0.75	0.25	0.25	0.75	0.25	0.75	1	3	2	0.86006426
47	0.25	0.75	0.75	0.25	0.75	0.25	1	6	2	0.57391456
48	0.25	0.75	0.25	0.75	0.75	0.25	4	6	2	0.59651631
49	0.75	0.75	0.25	0.5	0.75	0.25	4	6	0.345	0.5381402
50	0.75	0.75	0.25	0.75	0.25	0.5	1	3	0.345	0.78542539

Run	% Man BBG	% Man NBG	% Man Visual	% Man ES	% Man Update Tracker	% Man TMA	# Men TMA	# Men Pool	Machine Effectiveness	Resulting Score
51	0.25	0.75	0.5	0.25	0.25	0.25	4	5	2	0.75746317
52	0.25	0.25	0.25	0.5	0.75	0.75	4	5	2	0.62885725
53	0.75	0.75	0.25	0.75	0.5	0.75	3	6	2	0.49936421
54	0.25	0.75	0.75	0.75	0.75	0.25	3	6	0.345	0.53913317
55	0.25	0.5	0.25	0.75	0.25	0.25	1	5	1.1725	0.76869368
56	0.25	0.25	0.25	0.25	0.75	0.25	4	6	1.1725	0.57334446
57	0.25	0.25	0.25	0.25	0.5	0.5	1	3	2	0.87816763
58	0.75	0.25	0.5	0.25	0.75	0.25	4	5	0.345	0.63839886
59	0.75	0.25	0.25	0.25	0.75	0.75	1	3	0.345	0.77131623
60	0.75	0.75	0.75	0.75	0.25	0.5	4	5	2	0.69745856
61	0.5	0.75	0.25	0.5	0.25	0.5	1	6	2	0.68621551
62	0.25	0.75	0.25	0.25	0.5	0.75	4	3	0.345	0.69669303
63	0.25	0.25	0.75	0.25	0.75	0.75	1	6	0.345	0.46765684
64	0.25	0.25	0.75	0.5	0.25	0.25	4	6	0.345	0.69840393

Table 26 Input Factors and DOE input value matrix

The results for sensitivity to the input factors are shown in Table 26. The analysis was performed to find those factors and cross-factors that, at the 95 percent confidence interval, are not sensitive. Table 27 shows the sensitivity analysis of only those factors that have a probability of less than 0.05.

Term	Probability>|t|
#Men Pool(3,6)	<.0001*
%Man Tracker(0.25,0.75)	<.0001*
%Man TMA(0.25,0.75)	<.0001*
Machine Effectiveness(0.345,2)	<.0001*
%Man NB(0.25,0.75)	<.0001*
%Man Tracker*#Men Pool	<.0001*
%Man Tracker*%Man Tracker	0.0076*
%Man TMA*#Men TMA	0.0163*
%Man NB*Machine Effectiveness	0.0230*
%Man BB*%Man ES	0.0265*
%Man NB*#Men Pool	0.0336*
#Men TMA(1,4)	0.0422*
%Man Vis*%Man Vis	0.0455*

Table 27 Input Factors, Second Order and Two Level Cross Terms that demonstrate sensitivity

The DOE analysis was re-run only for those factors and cross-factors shown in Table 27. The resulting analysis is shown in Table 28 and Table 29.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Pro
#Men Pool(3,6)	-0.106413	0.003458	-30.7	<.00
%Man Tracker(0.25,0.75)	-0.05237	0.003302	-15.86	<.00
%Man TMA(0.25,0.75)	-0.04175	0.003348	-12.47	<.00
Machine Effectiveness(0.345,2)	0.027805	0.003181	8.74	<.00
%Man NB(0.25,0.75)	-0.023145	0.003126	-7.40	<.00
%Man Tracker*#Men Pool	-0.025457	0.003474	-7.33	<.00
%Man Tracker*%Man Tracker	0.0359093	0.010485	3.42	0.00
%Man TMA*#Men TMA	-0.010023	0.0034	-2.95	0.01
%Man NB*Machine Effectiveness	-0.009458	0.003459	-2.73	0.02
%Man BB*%Man ES	-0.009318	0.003516	-2.65	0.02
%Man NB*#Men Pool	0.0087327	0.003487	2.50	0.03
#Men TMA(1,4)	-0.008187	0.00346	-2.37	0.04
%Man Vis*%Man Vis	0.0228399	0.009848	2.32	0.04
%Man BB*Machine Effectiveness	-0.007459	0.0035	-2.13	0.06
%Man ES(0.25,0.75)	-0.006369	0.00309	-2.06	0.06
%Man Vis(0.25,0.75)	-0.006412	0.003428	-1.87	0.09
%Man BB(0.25,0.75)	-0.006086	0.003273	-1.86	0.09
%Man ES*#Men Pool	0.0048712	0.003533	1.38	0.20
%Man BB*%Man NB	-0.003956	0.003657	-1.08	0.30
%Man BB*%Man TMA	-0.003786	0.003554	-1.07	0.31
%Man ES*%Man Tracker	0.0035239	0.003424	1.03	0.33
%Man TMA*Machine Effectiveness	0.0033782	0.00333	1.01	0.33
%Man TMA*#Men Pool	0.0034914	0.003603	0.97	0.35
%Man NB*#Men TMA	-0.003361	0.003559	-0.94	0.36
%Man NB*%Man ES	0.0032943	0.003686	0.89	0.39
#Men Pool*Machine Effectiveness	-0.003052	0.003463	-0.88	0.40
%Man Tracker*#Men TMA	-0.003068	0.003622	-0.85	0.41
%Man Tracker*Machine Effectiveness	-0.002582	0.003431	-0.75	0.47
%Man Vis*#Men Pool	0.0026868	0.003791	0.71	0.49
#Men Pool*#Men Pool	0.0073168	0.011073	0.66	0.52
%Man Vis*#Men TMA	-0.00236	0.003648	-0.65	0.53
%Man TMA*%Man TMA	0.0046954	0.009613	0.49	0.63
#Men TMA*#Men Pool	-0.001745	0.003588	-0.49	0.63
%Man BB*%Man Tracker	-0.001734	0.003571	-0.49	0.63
%Man BB*%Man BB	0.0053553	0.011383	0.47	0.64
%Man ES*#Men TMA	-0.001647	0.003747	-0.44	0.67
%Man Tracker*%Man TMA	0.0015577	0.003599	0.43	0.67
%Man NB*%Man TMA	-0.001378	0.003594	-0.38	0.71
%Man Vis*%Man Tracker	0.001142	0.003487	0.33	0.75
#Men TMA*#Men TMA	-0.003036	0.01122	-0.27	0.79
#Men TMA*Machine Effectiveness	0.0009794	0.003724	0.26	0.79
%Man BB*#Men Pool	0.0009424	0.003617	0.26	0.80
%Man ES*%Man TMA	0.0007135	0.003383	0.21	0.83
%Man BB*#Men TMA	-0.000698	0.003556	-0.20	0.84
%Man Vis*%Man TMA	-0.000641	0.003643	-0.18	0.86
%Man ES*Machine Effectiveness	0.0004589	0.003333	0.14	0.89
%Man NB*%Man Vis	-0.000459	0.003462	-0.13	0.89
Machine Effectiveness*Machine Effectiveness	0.0014069	0.012424	0.11	0.91
%Man Vis*Machine Effectiveness	0.0003819	0.003412	0.11	0.91
%Man NB*%Man Tracker	-0.000353	0.003421	-0.10	0.92
%Man ES*%Man ES	-0.000862	0.010995	-0.08	0.93
%Man BB*%Man Vis	0.000265	0.003549	0.07	0.94
%Man NB*%Man NB	-0.000835	0.011599	-0.07	0.94
%Man Vis*%Man ES	0.0001938	0.003491	0.06	0.95

Table 28 Input Factors, Second Order and Two Level Cross Term Sensitivity Analysis

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Pr
#Men Pool(3,6)	-0.106813	0.002631	-40.	<.00
%Man Tracker(0.25,0.75)	-0.050579	0.002588	-19.54	<.00
%Man TMA(0.25,0.75)	-0.040332	0.002702	-14.93	<.00
Machine Effectiveness(0.345,2)	0.0287709	0.002575	11.17	<.00
%Man Tracker*#Men Pool	-0.025886	0.00279	-9.28	<.00
%Man NB(0.25,0.75)	-0.022305	0.002583	-8.64	<.00
%Man Tracker*%Man Tracker	0.0381427	0.00803	4.75	<.00
%Man BB*%Man ES	-0.009898	0.002774	-3.57	0.00
#Men TMA(1,4)	-0.009087	0.002611	-3.48	0.00
%Man TMA*#Men TMA	-0.008941	0.002873	-3.11	0.00
%Man Vis*%Man Vis	0.0202512	0.0076	2.66	0.01
%Man NB*#Men Pool	0.0073079	0.002762	2.65	0.01
%Man NB*Machine Effectiveness	-0.006186	0.002709	-2.28	0.02

Table 29 Reduced Input Factors, Second Order and Two Level Cross Term Sensitivity Analysis

Using JMP9®'s Desirability Maximizer function, the values shown in Figure 29 were determined as sensitive to the input factors.

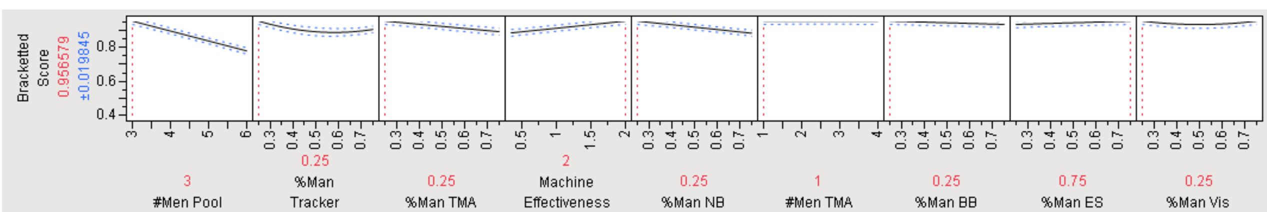

Figure 29 JMP Sensitivity Analysis

Input Factor	% Man BBG	% Man NBG	% Man Visual	% Man ES	% Man Update Tracker	% Man TMA	# Men TMA	# Men Pool	Machine Effectiveness
DOE results	25	25	25	75	25	25	1	3	2

Table 30 Input Factors from the DOE

It is noted that percent machine is equal to 1 minus percent man. Table 30 shows the data set that provides the optimum results of the model that produce an average utilization of CCS operators at 34.1%.

XVI APPENDIX D: UNTL TASK BREAKDOWNS

The UNTL was consulted as verification that the various identified Combat Control tasks were incorporated in the concepts and simulations. For the three scenarios, the task list was consulted, and provided Table 31 and Table 32. The L0 functions were supported by the UNTL task

L1 Capabilities →	Detect					Identify			Trk		Decide		Engage			Assess
L0 Functions →	Implement Directed Search	Process Acoustic Data	Process Image Data	Process ES Data	Process AIS	Assess Acoustic Data	Assess Image Data	Assess ES Data	Fuse Data	Perform TMA	Fuse Data	Develop SA	Advise Act	Supervise Act	Cue Sensors for Directed Search	Evaluate success of engagement
From UNTL list																
NTA 1 DEPLOY/CONDUCT MANEUVER																
NTA 1.1.2.3.1 Sail Ship from Port, Anchorage, or Moorage		1	1		1	1	1		1	1	1	1	1	1		
NTA 1.1.2.3.2 Return Ship to Port, Anchorage, or Moorage		1	1		1	1	1		1	1	1	1	1	1		
NTA 1.1.2.3.4 Conduct Convoy Operations	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
NTA 1.1.2.3.8 Conduct Submerged Operations	1,2,3	1,2,3				1,2,3			1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
NTA 1.2.11 Conduct Navigation	S	S	S	S	S	S	S	S	2	2	2	1,2,3	1,2,3	1,2,3		
NTA 1.2.12 Maneuver in Formation	S	S	S	S	S	S	S	S	S	S	S	3	3	3	3	
NTA 1.5.4.1.1 Conduct Screen	S	S	S	S	S	S	S	S	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	
NTA 1.5.4.1.2 Conduct Cover	S	S	S	S	S	S	S	S	2,3	2,3	2,3	2,3	2,3	2,3	2,3	
NTA 1.5.4.1.3 Provide Area Security	S	S	S	S	S	S	S	S	2,3	2,3	2,3	2,3	2,3	2,3	3	
NTA 1.5.4.1.4 Secure an Area	S	S	S	S	S	S	S	S	3	3	3	3	3	3	3	
NTA 1.5.7 Conduct Naval Special Warfare	S	S	S	S	S	S	S	S	2	2	2	2	2	2	2	
NTA 2 DEVELOP INTELLIGENCE																
NTA 2.1.1 Determine and Prioritize Priority Intelligence Requirements (PIR)	S	S	S	S	S	S	S	S	1,2,3	2	1,2,3	1,2,3				
NTA 2.1.3 Conduct Collection Planning and Directing	S	S	S	S	S	S	S	S	3		2,3	2,3	2,3	2,3	3	
NTA 2.3 Process And E3ploit Collected Information and Intelligence	S	S	S	S	S	S	S	S	1,3		1,3	1,3	1,3	1,3	1,3	
NTA 2.3.1 Conduct Technical Processing and E3ploitation	S	S	S	S	S	S	S	S	1,3		1,3	1,3	1,3	1,3	1,3	
NTA 2.4.1 Evaluate Information	S	S	S	S	S	S	S	S				1,2,3	1,2,3			
NTA 2.4.2 Integrate Information	S	S	S	S	S	S	S	S			1,2,3	1,2,3	1,2,3			
NTA 2.4.3 Interpret Information											1,2,3	1,2,3	1,2,3			
NTA 2.4.4.3 Evaluate the Battlespace Environment	S	S	S	S	S	S	S	S	3		3	3	3	3	3	
NTA 2.4.4.4 Evaluate the Threat	S	S	S	S	S	1	1	1	S	S	S	1				
NTA 2.4.4.5 Determine Enemy Courses of Action	S	S	S	S	S	S	S	S	S	S	3	1, 3	1, 3	1, 3	3	
NTA 2.4.5 Prepare Intelligence Products													1	1		
NTA 2.4.5.1 Provide Support to the Commander's Estimate	S	S	S	S	S	S	S	S	S	S	3	3	3	3	3	
NTA 2.4.5.2 Provide Intelligence to Develop the Situation	S	S	S	S	S	S	S	S	S	S	3	3	3	3	3	
NTA 2.4.5.3 Provide Indications and Warning (I&W) of Threat	S	S	S	S	S	S	S	S	S	S	3	3	3	3	3	
NTA 2.4.5.4 Provide Intelligence Support to Force Protection	S	S	S	S	S	S	S	S	S	S	2	2	2	2	2	
NTA 2.4.5.5 Provide Intelligence Support to Targeting	1	1	1	1	1	1	1	1	1	1	1,3	1,3	3	3	3	
NTA 2.5 Disseminate and Integrate Intelligence													3	3	3	

Table 31 UNTL Breakdown (Part 1)

NTA 3 EMPLOY FIREPOWER																
NTA 3.1.2 Select Target to Attack	S	S	S	S	S	S	S	S	S	S	1,3	1,3	1,3	1,3		
NTA 3.1.3 Select Platform(s) and System(s) for Attack	S	S	S	S	S	S	S	S	S	1	1	1	1	1	1	
NTA 3.1.4 Develop Order to Fire									S	1	1,3	1,3	1,3	1,3		
NTA 3.1.5 Conduct Tactical Combat Assessment	S	S	S	S	S	S	S	S	S	S	2	2	2	2	2	3
NTA 3.2.1.1 Attack Surface Targets	S	S	S	S	S	S	S	S	3	3	3	3	3	3	3	3
NTA 3.2.1.2 Attack Submerged Targets	S	S	S	S	S	S	S	S	3	3	3	3	3	3	3	3
NTA 3.2.5.1 Conduct Command and Control (C2) Attack	S	S	S	S	S	S	S	S	S	S	S	S	1,3	1,3	1,3	1,3
NTA 3.2.8.3 Engage Targets	S	S	S	S	S	S	S	S	S	S	S	S	1,3	1,3	1,3	3
NTA 3.2.8.4 Adjust Fires	S	S	S	S	S	S	S	S	S	S	S	S	3	3	3	3
NTA 3.2.9 Conduct Nonlethal Engagement	S	S	S	S	S	S	S	S	S	S	S	S	1	1	1	
NTA 4 PERFORM LOGISTICS AND COMBAT SERVICE SUPPORT																
NTA 5 E3ERCISE COMMAND AND CONTROL																
NTA 5.1.1.1 Transmit and Receive Information	S	S	S	S	S	S	S	S	S	S	S	1,2	3	3	3	
NTA 5.1.1.1.1 Provide Internal Communications	S	S	S	S	S	S	S	S	S	S	S	1,2	3	3	3	
NTA 5.1.1.1.2 Provide E3ternal Communications	S	S	S	S	S	S	S	S	S	S	S	1	3	3	3	
NTA 5.1.1.1.2.1 Receive and Transmit Force Orders											S	S	3	3	3	
NTA 5.1.2 Manage Means of Communicating Information											2	2	3	3	3	
NTA 5.1.3.1 Maintain and Display Tactical Picture	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	
NTA 5.1.3.2 Maintain and Display Force Command and Coordination Status	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
NTA 5.2 Analyze and Assess Situation	S	S	S	S	S	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3		
NTA 5.2.1.1 Review and Evaluate Situation	S	S	S	S	S	3	3	3	3	3	1,3	1,3	1,2,3	1,2,3	1,2	1,2
NTA 5.2.1.2 Review and Evaluate Mission Guidance											S	S	S	S	S	1,2,3
NTA 5.2.1.3 Review Rules of Engagement (ROE)											S	S	S	1	S	3
NTA 5.2.2 Decide on Need for Action or Change									S	S	1,3	1,3	1,3	1,3	1,3	
NTA 5.3 Determine and Plan Actions and Operations	S	S	S	S	S	S	S	S	S	S	S	S	1,2	1,2	2	2
NTA 5.3.2 Issue Planning Guidance									S	S	3	3	3	3	3	
NTA 5.3.4 Analyze and Compare Course of Action									S	S	S	S	1,2,3	1,2,3		
NTA 5.3.5 Select or Modify Course of Action									S	S	S	S	1,2,3	1,2,3		
NTA 5.6 Conduct Acoustic Warfare		1,2,3				1,2,3			1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3

Table 32 UNTL Breakdown (Part 2)

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